THE RECOGNITION OF MINERALS

BEING A COLLECTION OF NOTES
AND SIMPLE TESTS FOR THE
USE OF TRAVELLERS
AND PROSPECTORS.

BY

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WITH

MONOGRAPHS ON GEOLOGY,
ORE DEPOSITS, Etc.

BY

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PRICE 7/6 NETT.

The Mining Journal,
QUEEN VICTORIA STREET,
LONDON, E.C.

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* Readers are particularly requested to study both Preface and Intro before attempting to use the scheme for the Recognition of Minerals.

PREFACE.

THIS book is intended to assist the reader to distinguish minerals of commercial value from ordinary rocks and stones.

It is specially intended for persons who do not possess an intimate knowledge of minerals, but who may be travelling or residing in districts where mineral wealth exists.

It originated in a series of notes that I made to remind myself of the characters of commercial minerals when I was going to Ashanti in 1900. I added to it during professional journeys to Tasmania and elsewhere, and I hope that the information may be useful to prospectors, mining students, and travellers.

Apart from those already engaged in seeking or mining for various minerals, there are large numbers of English-speaking men who every year are residing in or passing through mineralised districts in various parts of the world.

It is largely to this class that I address this book, and I venture to believe that some time spent in acquiring practice in the use of the "pan" and the blow-pipe, and in the recognition of minerals by their appearance, will repay them in the added interest that such study gives to residence abroad under conditions that are sometimes monotonous or unprofitable.

The history of many successful discoveries shows that familiarity with a book of this scope would have led to the discovery of many valuable mines by other and earlier explorers.

I have intentionally abstained from dwelling at length on methods of assay; partly because this book is intended for observers in the field who have not the appliances for such work, and also because assays on which the investment of capital depends ought only to be carried out by those who have been properly trained for such work.

The observer in the field should, however, learn how to identify minerals, at least those of common occurrence, and should seek assistance in the case of those that he cannot identify, and he should learn how to take samples correctly and how to record his observations. When he has learnt to do this satisfactorily and accurately he will find that there is no great difficulty in obtaining the necessary expert and financial assistance to prove and develop his discovery.

The information now given includes a description of most minerals of commercial value, and how to recognise them, their general market value, the uses to which they are put, and the demand which usually exists for them. It furnishes a fairly complete skeleton or frame-work of the subject, which every man can clothe for himself with such experience as may come his way.

It is hoped that as it stands the book will enable any one to take any kind of mineral, rock, stone, or sand, and to form an opinion whether it is of commercial value or not. This cannot, of course, be done, in most cases, by a mere inspection, and I have therefore included all such simple tests as can conveniently be performed in the field. When any mineral is found that cannot be identified, and more particularly if it has any points of resemblance to any of the more uncommon minerals, as, for instance, the ores of uranium, the rare earths, &c., it should be sent to a professional analyst for examination.

I have adopted the plan of classifying by colour simply because I find it handy and believe others will do the same. These notes have recently been published in "The Mining Journal," and I have received many letters giving me hints and corrections. I hope that every reader who finds the book of use to him will kindly write to me and send any additional information or corrections that occur to him.

The reader should study both this Preface and the Introduction that follows before attempting to make use of the tables for the recognition of minerals.

• In addition to the valuable monographs by Mr. Donald MacAlister, I am indebted to Mr. Leopold Claremont for much information on the gemstones, and to Mr. Stephen J. Lett Mr. John S. Sellon, and many others, for many hints and corrections. Mr. T. C. Cantrill, B.Sc., has kindly read the geological sections in proof, and Mr. C. O. Bannister has kindly read the proofs of the remaining sections.

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INTRODUCTION.

As this book is intended as a simple guide to the recognition of minerals for those who have had no special training in mineralogy I have endeavoured to use as few technical terms as possible and to give an explanation of those that cannot be avoided.

The book is not in any way a complete manual for prospectors and still less a textbook of determinative mineralogy. If a complete work of that nature had been undertaken, it would have been necessary to include sections on geology, crystallography, methods of analysis, etc., which could only have been dealt with in three or four substantial volumes, and the whole ground is already covered by well-known textbooks of acknowledged authority.

The object of this book is merely to provide *an elementary guide to the recognition of the minerals that possess commercial value.*

To attain this end I have endeavoured to *contrast the characters* presented by the *commercial minerals* with those of the *common (commercially worthless) rocks and stones* in which or among which minerals are found.

In order that an unknown mineral or stone may be quickly identified, all those of *similar appearance* are classified into groups, without reference to their composition. Thus all *black minerals* appear in a group by themselves, all *red* ones form another group, all minerals having a metallic appearance are grouped together, and so on.

Where a mineral (as is often the case) may be of different colours, it is described fully under the colour that is the most common, but it is also referred to under *all* the other groups in which it may appear.

Thus cassiterite is most often *black*, and is fully described under "Black Minerals," but it may also be brown, ruby-coloured, amber-coloured, grey and white, and is consequently also mentioned under these sections.

This method of grouping according to colour is, of course open to objections, the chief of which is perhaps that many minerals occur of such widely differing colours in different localities that a system based on the grouping together according to colour may be considered likely to confuse the reader. If, however, it is carefully borne in mind that the system should not be allowed to influence the final judgment until confirmatory tests have been applied, and that it is simply adopted for convenience, I believe it will commend itself to the reader, even though it may be an unscientific method of dealing with the subject.

The well-known writer on mineralogy, E. S. Dana, gives a short list of the colours of minerals in his Textbook of Mineralogy, and says as follows:—"The following lists may *be of some use in the way of suggestion. It is* to *be noted,* however, that, especially in the case of metallic minerals, a slight surface change may alter the effect of colour. Further, among minerals of unmetallic lustre particularly, no sharp line can be drawn between colours slightly different, and many variations of shade occur in the case of a single species. For these reasons no lists, unless inconveniently extended, could make any claim to completeness."

He then gives separate lists of the minerals possessing metallic lustre, and of those that do not.

I have extended the colour groupings given by Dana, so as to include as far as possible *all* minerals of *commercial value*, but have intentionally omitted a few that occur too sparingly to be of commercial consequence.

Those who fear that they may be misled by the colour classification can disregard the colour scheme altogether and proceed with the general method of testing. It is advisable for the reader to familiarise himself with the appearance of minerals by examining collections, and he should compare the descriptions given in the book with actual specimens, of at least 50 or 60 of the more common ores. If he carries out some tests on these, he will feel more confidence on setting out to do actual work in the field.

A suitable collection may be obtained very cheaply, and it is much better to have typical specimens than to purchase selected specimens such as are often seen in museums, which are often chosen for their beauty or for the perfection of their crystalline structure.

Many of the metallic ores are readily distinguished from common (*i.e.*, worthless) rocks and stones by their appearance or their weight. This rule does not, of course, always hold good, and it is particularly in such cases that the reader should take pains to carry in his mind's eye the characteristics of certain valuable minerals that might otherwise pass unnoticed.

A great number of the ordinary rocks and stones are either brown or grey of varying shades, whereas but few of the commercial minerals do not possess distinctive features, either of colour, structure or weight.

The colour-groups consist of short descriptions of each separate mineral, and give its different names, its composition, the colour of its streak (*i.e.*, the colour of the powdered mineral), its specific gravity (that is to say, its relative heaviness compared to water), its hardness or softness, the effect of blow-pipe tests, and the action of water and acids.

These descriptions, of course, apply to a piece of mineral which consists all of the same kind. If a specimen under examination obviously consists of two or more minerals, it must be so broken as to obtain clean pieces of each constituent, or the mineral must be powdered and the constituents separated by panning.

For example, it is often the case that an ordinary looking rock or stone contains a commercial mineral disseminated through it. The mineral portion may be visible to the naked eye, or it may be so finely divided as not to be visible even with a powerful lens. Thus some gold ores contain coarse gold which is readily visible, in other cases the gold is so fine that it can only be seen by powdering and panning; and in cases where the gold is contained in pyrites, it would seldom be recognisable without resorting to a fusion.

In cases where the mineral under examination is a mixture of two or more substances of the same specific gravity, panning will not, of course, be effectual in producing a separation. For instance, cassiterite and wolfram are so nearly alike in specific gravity that they cannot be properly separated in this way. On the other hand, supposing that a specimen consisted of a mixture of quartz and scheelite, whose specific gravities are widely different, though the colour of each is white, a separation can be effected, and it can be seen that two different minerals are present, even though both of them are white in colour, as the heavier scheelite will form a "head" in the pan, while the quartz will be carried back to the "tail" by the water.

Again, in the case of any rock containing cassiterite, a separation from the accompanying rock can be readily effected in the pan on account of the difference in the specific gravities. The "head" would be collected, and dried, and on treatment before the blow-pipe would yield a bead of metallic tin.

After a mineral has been identified, reference should be made to the monograph on the chief metal or element it contains, where information will be found respecting its market value,[*] the demand that ordinarily[*] exists, its applications, and the state (degree of purity or condition) to which it must be dressed for sale.

A list of minerals is also included, classified according to whether they are—

(1) Soluble in water.
(2) Soluble in hydrochloric acid.
(3) Soluble in aquaregia.
(4) Insoluble in water and the above acids.

Some notes on prospecting, panning, on the taking of samples, the general operations of mining and dressing, and on the treatment of gold ores, are also included.

Special attention is directed to the *directions for taking of samples*, and on the *noting the conditions* under which the deposit occurs.

These matters are of the highest importance, and notes should be carefully made in writing and measurements recorded on the spot. Unless there is good evidence that the samples were carefully taken, capital cannot be invested safely in proving or working an alleged discovery, and unless the conditions under which it occurs are fully described, it would in many cases be impossible to form a conclusion whether the deposit could be worked to a profit.

When a deposit of a mineral has been recognised the information obtained should be clearly set out in writing and carefully revised, so as to prevent accidental omissions of necessary particulars. If it is desired to work it, either with the proprietor's own capital or with financial assistance, samples and particulars should next be submitted to a professional analyst, and his certificates, together with the prospector's notes, should be submitted to a mining engineer.

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[*] These are matters of considerable importance, as the prices of some minerals vary a good deal, and what is low priced to-day may soon be of value in consequence of a new application being discovered.

This is essential to safety, and, in cases where external help is required, has the advantage of providing at the outset a safeguard that would be required inevitably at some stage of the proceedings before money was raised. The mining engineer is usually able to introduce the property to investors, whose action would be guided in any event by his advice.

Speaking generally, almost every metal and mineral described in this book has a commercial value, depending on its purity, the conditions under which it occurs, and the demand for it at the time being. In those cases where it has been impossible to give this information in this book, or where it is questioned whether the information given represents the state of the market at the time, I shall be happy to give the necessary information.

Even the lower grades of the more common metals possess a value if they are present in large quantities under favourable conditions for working; for instance, a copper ore containing from 2 to 3 per cent., if other conditions were favourable, would be a valuable property. A tin ore containing under 0·2 per cent. is being successfully worked on a large scale, and gold in alluvial deposits has been made to pay well even when there were no more than 2 to 3 grains (*4d.* or *6d.*) to the cubic yard.

An ordinary looking sample of galena may carry a large percentage of silver and a sample of common iron pyrites may contain large quantities of gold and silver. Some of the telluride ores, which are very similar in appearance to ordinary pyrites, are very rich in gold and silver.

Tantalite, which is worth some 3*s.* to 4*s.* a pound, is in appearance often very like hæmatite, the common ore of iron, pitchblende and thorianite might both be mistaken for *wolfram,* which is itself when dressed for market worth £100 a ton, while the two fore-mentioned are very much more valuable.

There are many ores that may be overlooked as not possessing a marked metallic appearance, such as scheelite, cerussite and "horn" silver. Again, other deposits such as deposits of the alkalis, china clay, phosphatic rocks, &c., all possess a value according to their extent and position as regards working facilities and transport.

The conditions under which minerals occur, that is to say facilities for working, water power, labour, transport, &c., have an important bearing on their commercial value and should receive careful attention. I would direct the attention of the reader to these points specially, as if when he has located a mineral deposit, he is able to furnish full particulars of the nature referred to, it will greatly assist him in getting the financial support necessary for its development.

As mentioned in the Preface, I shall at all times be grateful for suggestions and corrections for the improvement of this book.

PROSPECTING.

The term "prospecting" means searching for workable deposits of the commercially valuable minerals, including precious stones, and the person engaged in such a search is termed a "prospector." In many cases such a prospector is engaged for the purpose of searching for a particular mineral or metal, such as gold, tin or copper ores, etc., or he may be engaged in a general search for all or any part of the commercial minerals. Sometimes he is engaged by a company who make arrangements for the systematic assay of all such specimens as he may discover; in other cases he may be acting on his own behalf, in which case he has to depend largely on his own knowledge and experience in order to select out of a large number of specimens those that he believes are worth having assayed. In the latter case, particularly, it may often happen that he may discard various specimens which do not present characters that are familiar to him, and may so miss recognising deposits which would have been of value.

He is also frequently led to devote much time and attention to tracing out various specimens that a wider knowledge would have enabled him to recognise as of no commercial value.

In a country that has been surveyed geologically or in which mining has already been undertaken* he is often able to obtain much useful information from published maps and reports or by studying collections of specimens.

In cases where no mining has been undertaken he may be able to gain information by showing to the inhabitants specimens of the various commercial minerals and the rocks in which they occur, and asking whether anything like them has been seen.

The prospector should have a good experience in the use of the pan or the vanning shovel, and if to this he adds a knowledge of the use of the blowpipe and the effect of acids on the commoner commercial minerals, he will feel a greater certainty of not passing over deposits that he might otherwise miss.

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* Ancient workings, dumps, or slag-heaps should be carefully examined.

In countries that are covered with dense vegetation prospecting is a matter of great difficulty, and has to be confined largely to the roads or native tracks, and the examination of rivers, watercourses and beaches.

In such cases the prospector should be on the alert to examine any fresh tracks, road or rail cuttings that are being made, and should interview those at work on them and enlist their assistance. Comparatively small excavations such as are required for fence-posts, for wells, or water-races have frequently resulted in the discovery of minerals, and the cutting of a road or railway in a mineralised country affords an admirable opportunity of examining the geological structure of a country and a very good opportunity of actually discovering the outcrops of lodes. The natural cuttings caused by rivers and watercourses should always receive particular attention, and the marshes at the foot of hills are fruitful sources of alluvial deposits. The examination of marshy ground and of river-beds is naturally best undertaken at the driest season of the year, and the hills and higher ground can be examined in wet seasons when the low-lying ground is water-logged.

The prospector should bear in mind that certain minerals are usually associated with certain geological formations, though in this respect he should keep an open mind and not conclude too hastily that a particular mineral cannot exist in a given locality because he does not find the geological formations with which it is generally connected.

As the majority of valuable metals and metallic ores occur in lode formation, it is most important for the prospector to familiarise himself with their appearance.

The outcrops of lodes are characterised by the quartz, "gossan," "peach," "capel," and oxidised or unoxidised minerals. These are all described in subsequent sections. In some cases where the lode outcrops freely at surface it is unmistakable, and merely requires to be traced as far as possible and sunk on or driven on in order to ascertain its contents. Many lodes, on the other hand, do not outcrop so distinctly, and the indication they give of their presence may be limited to a few quartz stringers, or altered patches in the country rock; or, instead of quartz, peach or other veinstones may be present; or when large quantities of

sulphides were originally present, the lode may be so rich in oxidised iron, etc., that the outcrop seems to be a mass of iron ore.

Sometimes the lode carries mineral in more or less quantity right up to "grass." In other cases the capping may be barren quartz, gossan, or quartz mixed with oxidised iron or with pyrites, and may carry no mineral of value, but on sinking four or five fathoms the mineral that it may carry in payable quantities may make its appearance. The finding of "shoadstones" or of alluvial minerals may result in the discovery of lodes otherwise concealed by surface *débris*. These are generally, but not invariably, found on the lower side of the lode; and chiefly in the case of minerals that are not at all or only slightly affected by weathering, such as gold, cassiterite, wolfram, etc., often make it possible to find the lode even if it is covered by earth and vegetation. The final determination of the presence of the lode in a practical way is by costeening or sinking a series of pits at regular intervals in such a manner as to cut across its supposed course. A shaft should then be sunk on the lode, or if it occurs on the side of a hill it may be convenient to drive on the lode. At every few feet in the shaft or drive the lode matter should be sampled and tested.

In sampling, the sample should be taken so as to include the whole face exposed, as it often happens that one portion may be richer than another; for instance, there may be a pay-streak in the middle of the lode, or the mineral contents may be concentrated towards the footwall or hanging wall, so that unless the sample is taken impartially all over the lode, the results obtained on assay will be deceptive.

The whole sample taken should be mixed, and the larger pieces broken and mixed in. The pile is then divided in four quarters and two opposite portions discarded. The two remaining quarters are further broken, mixed, and quartered again, and this procedure is repeated until the quantity is reduced to an amount convenient to grind for assaying.

For sampling dumps it is necessary to dig right through them in order to get accurate results, as the interior or one side may be much poorer in mineral than the rest. It must also be remembered that some minerals, such as copper, lead, etc., are much affected by "weathering."

In sampling an alluvial deposit even greater care is necessary in order to obtain correct results, for the reason that in most cases the mineral is concentrated in the lowest layer, or there may be more than one layer, so that any pits or bores that are sunk must be put down to "bottom" or "wash."

In sinking a pit in wet ground it is difficult to ensure getting exactly the proper proportion of the lower wet (and generally gravelly) material to the upper portion, on account of the running of wet sand and gravel, but, where it is possible, pits are more satisfactory than bores. Bores in wet ground must be tubed, and even then they are liable to give erroneous results.

Whether pits or bores are made, it is best to mix thoroughly the whole of the material that comes from each pit or bore, and to test it in a sluice box. Very many erroneous figures have been obtained by examining the lower portions only, which are in nearly all cases the richest. In most alluvial workings the whole of ground, over-burden as well as the pay-gravel, has to be removed and washed, and therefore it should all be mixed before assaying.

Before commencing work in the field the prospector will find it an assistance to be able to recognise some of the more important rock formations that he may meet with, and hence the following brief account of the sedimentary rocks, the igneous rocks, and the lodes and other mineral bearing formations has been included. In this section will be found a brief description of all the more important rocks, their appearance and characters and the relation they bear to one another, and the mineral formations that are found to occur in them.

While many important discoveries have been made entirely by chance and not as the result of systematic prospecting, everyone who has actually worked in the field will find a distinct advantage in possessing some geological knowledge, even of an elementary character, which he can supplement from time to time as his experience increases.

SEDIMENTARY, IGNEOUS, AND METAMORPHIC ROCKS.

BY DONALD A. MACALISTER, Assoc.R.S.M., F.G.S.

SEDIMENTARY ROCKS AND LIMESTONES.

The term "rock" is used by geologists to signify any heterogeneous aggregate of mineral substances entering into the composition of the earth's crust.

The greater number of rocks usually met with are mere mechanical mixtures of fine or coarse grains of minerals which were derived from pre-existing rock-masses of which the crust of the world was originally composed.

Marine Sediments.—By far the greatest accumulations of such materials took place at the bottoms of seas in the neighbourhood of continents or other land areas. The actions of heat, frost, rain and other natural agencies are the prime causes of the destruction, disintegration or decomposition of the dry land, and as this detritus was carried down by rains and rivers to the sea, it was deposited layer by layer at varying distances from the shore, according to the size of the grains and the carrying power of the water, or to the buoyancy of the material so transported. As examples of this kind of action we see that round modern shores and in river valleys the material is frequently coarse owing to the ability of running waters to transport comparatively large fragments, while out at sea only the finest muds or sands are found in the depths. All rocks formed in this way are called "sediments."

The ancient shores also suffered through the incessant attacks of the sea, and must have presented a rugged outline

and cliff profile with seaward extensions of a denuded rocky floor, or coastal platform, covered with coarse rolled detritus like many sea coasts of modern land areas. These sediments gradually by infiltration of cementing materials became consolidated into hard rocks. Geologically speaking, the soft sand or mud is as much a "rock" as the hard mass into which it consolidates. It does not require much imagination, therefore, to conceive of sedimentary rocks formed by actions which may be regarded as modifications of the foregoing. Thus there are lake deposits and deposits in upland hollows. Some sediments have been laid down uninterruptedly through long periods and consequently are remarkably uniform. Others were deposited periodically and under varying conditions so that the successive layers have a varying composition obvious to the eye. Generally speaking, the fine-grained deep-sea deposits are of greater extent and more uniform layer by layer than are the deposits near the land, while those on the coastal shelf and in river valleys are variable, consisting of muds, sands, and conglomerates.

Subaërial Rocks.—Deposits of blown sand are sediments formed by subaërial agencies alone, while still another class of deposit is typified in the angular talus and scree slopes on the flanks of mountain ranges. Such deposits have small chance of ever building up large rock masses, as they are themselves being constantly worn away and transported seawards. The boulders and clays or the moraines of glaciers, and also the masses of rotted fragmentary surface rock known as "head," may be included in these latter unstratified deposits.

General Observations on Sedimentary Rocks.—For the sake of the intelligent understanding of the main geological conceptions it may be briefly remarked that the depositions of the earliest known sediments commenced, on the estimation of eminent geologists, at anything from fifty to two hundred million years ago; that is to say, when the physical conditions of the cooling globe commenced to approximate to the physical conditions of the present time. The world is supposed to have been once a molten whirling mass which gradually cooled and consolidated from the surface inwards, and as it did so it became contorted and wrinkled by the conflicting stresses to which it was subjected. The con-

sequence of this was that the higher land formed immense continental areas, the permanence of which, with the exception of oscillations above and below the sea, appears to be attested by the ancient schistose massifs of present continental areas of the globe with their corresponding deep-sea depressions. In addition, however, to these actions giving rise to the primary continental rock floors, certain geological epochs ranging from the time of the oldest known sediments to those of comparatively recent date have been characterised by a crinkling and folding of the earth's crust by crustal movements, so that sedimentary deposits which were once below the sea have been raised bodily above it, or have been folded upwards into mountain chains and plicated, overthrust and faulted until the rocks in some cases composing them, although once below the sea, are now miles above it. Such disturbances have generally taken place along certain lines of crustal weakness, either in the form of a continental uplift or submergence, or as a thrusting along certain lines frequently accompanied by volcanic phenomena. These periodic disturbances have therefore been the cause of raising above the sea at different times sedimentary deposits formed previously round a still older land area, with the result that new land areas were formed, consisting of newer sedimentary rocks which were again worn away by weathering action just as were the older rocks from which they were derived. It is evident, therefore, that sedimentary rocks may be derived from not only the oldest known rocks, but likewise from rocks which were themselves formed under precisely similar conditions and perhaps differing but slightly from them in age.

The determination of the age of the sedimentary rocks is based on various considerations, the most important of which is superposition, the oldest rocks being the lowest. In folded and disturbed regions the estimation of the age of the rocks is not possible by the mere study of the superposition, so must be determined by fossils (*i.e.*, the buried and preserved harder parts of organisms contemporaneous with the rocks in which they are found); or by mineral composition, by which the older masses from which the material of the rock was derived may often be determined. With regard to the distribution of fossils it should be recollected that there are comparatively few fossil land animals found, since the bodies of land animals

are broken up and carried away seawards with the ordinary superficial detritus, and have but little chance of being buried and preserved. Where fossils are obtainable, they are generally marine or freshwater fauna, but the comparative age and conditions of deposition of the stratum in which the various species occur may, by an expert, be determined well enough for all practical purposes by even a single fossil, or quite accurately from the fossil assemblage in the bed.

Geological Formations.—The prospector as a rule is not concerned with the determination of the ages of the rocks in which he expects to find mineral deposits, and it is usually sufficient for him simply to be able to recognise their chief characters. Indeed, in all but remote regions geological maps are obtainable which render this branch of the work superfluous. Since, however, the representation of the various formations as indicated by colours on a geological map, is based both on the age and nature of the rocks, the following brief notes should be of interest to the inexperienced.

It should be recollected that in no one country is there an unbroken succession of sediments indicating continuous depositions through all geological time. Not only have there been at various times intervals during which sedimentation has been suspended but also prolonged periods of denudation, so that some formations have wholly or in part been worn away again. With the newer and softer rocks the effects of denudation are most marked, and it is by this denudation that the older rocks, their geological structures, and the mineral repositories they contain are revealed to us. By careful mapping and study of the entombed remains of extinct organisms (generally shells) which flourished at the time the beds in which they are found were being formed, geologists have been able to construct a general tabular statement (or Stratigraphical Table) based on age. The names given to the various formations are modified from those of districts which typically represent them. A departure in nomenclature is sometimes made so as to indicate the age by the principal fossils found in them.

A brief detailed account of the age-classification of rocks would be useless to the prospector, since the character of rocks of the same age differs widely in different parts of the

globe and even in the same district. Shortly stated, however, the following names indicate the principal Age-groups which geologists further divide and sub-divide *ad infinitum*. The most ancient rocks are those called the Archæan. They consist of sheared igneous rocks, gneisses and schists, and a few sediments. Upon them were laid the Cambrian, Ordovician and Silurian (collectively—the Older Palæozoic); Devonian, Carboniferous and Permian (Newer Palæozoic); the Triassic, Jurassic and Cretaceous (Mesozoic or Secondary); finally, the Eocene, Oligocene, Miocene, Pliocene, Pleistocene, and recent (Cainozoic or Tertiary).

On geological maps these groups are represented by distinctive colours, and in order that the various formations in each group may be clearly indicated, various shades of these colours are chosen so as to represent the various beds of shales, sandstones, limestones, etc., composing them.

In maps, therefore, it will be found that a sandstone of the Devonian period is indicated by a different colour from a sandstone in the Carboniferous, and so with all the rocks. Colours have sometimes to be repeated owing to the difficulty in preparing tints. The igneous rocks are generally indicated by brilliant colours suggesting their fiery origin or the bright tints they possess. There is always a tablet index at the side of the map to explain the meaning of the colours. In addition various symbols or index letters are employed, the use of which is indicated in the tablet.

Faults and Folds.—Apart from their various compositions and general characters, the sedimentary rocks may display certain structures brought about by the crustal disturbances mentioned above long after the rocks were formed. Particularly is this the case with many of the older rocks which have been affected by all the different movements which have taken place in the districts in which they occur. The newer rocks, on the other hand, have, of course, been affected only by the more recent of the disturbances. Although many Tertiary sediments have been disturbed to an astonishing degree, they seldom present the profoundly *altered* types seen in many of the Palæozoic rocks. In the Tertiary rocks the effects of crustal movements are exhibited in the flexures or dislocations, while the general characters of the rocks have usually been preserved. The bending may have taken the simple

forms of undulations in which the strata are bent into anticlines and synclines—the anticlines representing the crests, and the synclines the troughs of the undulations. In more extreme cases the strata are buckled right up and overturned. When this happens there may have been also an actual break or tear along the folds, so that the rocks are pushed forward over themselves. In a large way a section taken through a mountain range which has been merely excessively buckled would show that the folds generally diverge upwards in irregular fan-shapes, traversed by numerous planes of dislocation, and the range as a whole has an anticlinal arrangement.

In many of the other disturbed rocks, on the other hand, the conditions suggest that they were buried at the time of the movements beneath a great weight of overlying rocks, as the folding and tearing has been so intense that the whole character of the rocks has been changed. Here the folds have been so flattened out that they are no longer recognizable as such, while the softer beds have been sheared, drawn out, and completely altered in character. In other cases complex and irregular folds can readily be made out by the contortions of the various beds, but the whole is traversed by planes of cleavage which cut across the formation independent of the position or character of the beds composing it. This cleavage is a phenomenon brought about by intense lateral pressure, and although it generally has a uniform direction, there are frequent changes in dip, varying from a vertical to a horizontal position, which may coincide with, or be entirely independent of the original planes of bedding of the rock. Very hard bands such as quartzites and igneous dykes, do not readily take on this cleavage, but, instead, are broken up and drawn out into lenticles.

A Fault is a break in the continuity of rocks by means of a fracture followed by dislocation. These dislocations may be due to "thrusting" or to "normal faulting." A thrust fault is a dislocation produced by fracture during great compressive strain, so that the rocks on one side of the fault are thrust or pushed over the rocks on the other side.

As a rule the plane of thrusting is inclined at a low angle to the horizon, and generally strikes in the same direction as the beds. The material in its vicinity is usually broken and sheared, and it may contain crush-conglomerates and breccias.

In normal faulting the dislocations are due to the sinking of the rocks on one side of a plane of fracture so that their continuity is broken. The phenomenon is not necessarily brought about by the crustal movements mentioned above, but may be due to less profound movements of adjustment of the rocks to local strains. They may occur either in the direction of strike of the rocks or across them, and they are usually highly inclined to the horizontal. Many lodes are due to the mineralization of faults which in turn may be dislocated by newer faults.

Field Observations.—After the presence of a mineral deposit has been proved and samples roughly tested from the deposit itself or from loose material lying about, the next step is to ascertain the extent and true value of the find as a mining concern, both from the point of view of the richness of the deposit and the local facilities for working it. Mr. Moor has dealt with the latter in the section entitled: "Conditions under which Mineral Deposits occur" (p. 199), so that it need only be recalled here. The other problem the prospector has to face is how to test the deposit thoroughly with minimum expense and trouble to himself. This should be carried out in two ways. One way is the method of the miner as already described by Mr. Moor in the section entitled "Prospecting" (p. 4), and the other is the method employed by the geologist in any preliminary survey. It is here that the value of a knowledge of the mode of occurrence and common mineral associates of the rock types comes in. For the purposes of a preliminary survey, the prospector should obtain or prepare a topographical map. He should also carry a magnetic compass, protractor, pocket lens, a half-pound hammer and a bottle containing hydrochloric acid (10 per cent. solution). The scale on which the map is drawn may be too small to allow of notes being made, and in that case a larger scale map must be prepared of about six inches to the mile, with the true north and magnetic north indicated. With this simple equipment the prospector will commence to traverse the whole district near the deposit, carefully noting the characters of all the rocks by walking to and fro, so as to cover all the ground. At the end of a few days there will be a sufficient number of notes to enable him to delineate on the

map the various kinds of rocks met with, and to indicate the occurrence of fresh finds of the mineral for which he is searching. The apparatus carried enables him to differentiate the shales, sandstones, limestones, schistose, and contact altered rocks, together with dykes and other igneous masses intruded among them. The characters of these various rocks should be carefully noted if specimens are not collected. Strange rocks or minerals which cannot be identified in the field can be examined at leisure at headquarters. In making the survey the greatest attention should of course be given to the occurrence of the mineral itself and to the occurrence of the materials with which it is known to be associated.

With this brief introduction, the main kinds of sedimentary rocks may now be described.

Sandstones, etc.—The group of rocks conveniently classed under this heading comprises sandstones, grits, quartzites, conglomerates and other fragmental rocks. Although generally consisting of granular siliceous minerals of different kinds they are variable as regards texture and composition, and if they contain excessive amounts of argillaceous materials may merge insensibly into shales or mudstones. As a rule they consist of the most indestructible grains of the rocks from which they are derived. A distinction is sometimes made where the cementing or interstitial material of the grains forms a considerable proportion of the rock.

Sandstones are composed mainly of quartz in small rounded or subangular grains, the interstitial spaces being filled with smaller grains or some cementing material. When the grains are angular the rock is termed a grit. Other minerals which may be present are mica, felspar, hornblende, and augite, together with rarer minerals occurring in subordinate amounts, such as tourmaline, garnet, zircon, etc. The grains may be cemented together by silica (quartz) derived largely from the grains themselves, so that the rock as a whole is a tough siliceous aggregate termed a quartzite.

Some sandstones are cemented by carbonate of lime or by ferruginous compounds in which kaolin may form a not unimportant constituent. Such varieties are termed ferruginous, calcareous, or argillaceous sandstones, etc.

When sandstones have a porous texture they sometimes

become impregnated with ores by the infiltration of sulphurous or oxidic metalliferous solutions from lodes, as in the famous lead-bearing Bunter sandstones of Bleiberg. The flexible sandstone of Brazil, termed itacolumite, owes its peculiar property to the partial cementing of the constituent grains, and to the presence of a large proportion of flexible minerals, *e.g.*, mica thus giving a certain amount of play between the uncemented grains.

Conglomerates are accumulations of pebbles or boulders generally rudely stratified. They consist of pebbles of quartz and the harder parts of the rocks of the neighbourhood in which they are found. There is generally a good deal of interstitial sandy or clayey material, and although not always of great extent the conglomerate deposits are frequently of value commercially owing to their containing valuable heavy minerals, such as tinstone, wolfram, gold, platinum, &c., which have been concentrated as a heavy residue from the weathered rocks from which the conglomerate itself was formed.

Beach deposits of heavy minerals are occasionally found. In Alaska gold, in Cornwall tin, and in Brazil monazite occur as seashore concentrates.

Conglomerates were formed under shallow-water conditions, such as obtain in rivers and seashores, so that their occurrence frequently represents a stratigraphical break.

The Witwatersrand gold-bearing series of South Africa consist of schists, quartzites and quartz conglomerates of great age. They appear to be infolded with Archæan rocks. The ancient cupriferous conglomerates of Lake Superior may be cited as another important conglomerate deposit impregnated with useful ore.

Shales and Mudstones. — These rocks consist mainly of argillaceous or clayey material. Their fine-grained nature indicates that the conditions under which they were deposited is that of still, generally deep, water. In estuarine and lake deposits, beds of mudstones and shales alternate with sandstones and silty layers. Unlike sandstones, they do not show "false" or current bedding although often occurring as layers among estuarine sands and river gravels.

Shales and mudstones are typically deep-sea deposits. They are generally dark in colour owing to the presence of sulphur compounds or organic matter. In texture, degree of fissility,

colour, hardness and general structure, they show considerable variations. Nodular or concretionary structure is not unfrequently represented where the muds contain originally iron or manganous compounds or calcareous or organic matter. In a few cases the shales may be of great value owing to the presence of bitumen, which can be extracted by heat. Occasionally, as in Mansfeld, they are impregnated with ores, and where carbonaceous shales are intersected by lodes there is sometimes an enrichment of the lode at the points of intersection.

The principal constituents of shales are minute fragments of such minerals as quartz, felspar and mica, embedded in kaolin or an extremely fine impure micaceous substance resembling clay, but which is now regarded as an alteration mineral developed *in place.*

A red clay occurring at enormous depth in the ocean consists of decomposed volcanic dust, together with minute animal remains, such as those entering into the composition of radiolarian shales and cherts.

When the deposit is mainly composed of the siliceous skeletons of diatoms it becomes of value in the manufacture of explosives, and goes by the name of Tripoli, Barbados earth, infusorial earth and diatomaceous earth. Such deposits are commonly formed in lakes.

China clay is a pure white kaolin or aluminium silicate resulting from the decomposition of the felspar of granite.

The ordinary roofing slates consist of the same kind of material as shales, but they have well marked planes of cleavage which unlike the shales bear no relation to the planes of bedding, and in fact generally cross them. The cleavage is a character induced by pressure, and all slaty rocks occur in regions which have been subjected to earth movements. This also accounts for the fact that the dip of the cleavage of slates is generally highly inclined. The Palæozoic shales and slates of Cornwall and the Isle of Man are locally known as Killas, a term which is now in common use.

Limestones.—Like shales and sandstones, the limestones often contain much impurity, but unlike them they are composed for the most part of the skeletons of organisms which once lived in the sea. In some cases they are chemical precipitates of carbonate of lime. Their structures are very varied. Where

the principal impurity consists of a large proportion of sand, the rock may be termed a calcareous sandstone or "calcarene." Where there is mud mixed with it the rock is known as marl. The calcareous material is often accompanied by carbonate of magnesia, a compound which is practically of universal occurrence in limestone.

Many limestones are seen to be composed of the shells of marine organisms, but others have been entirely reconstituted owing to the shells having been broken and dissolved some time after having been deposited. In particular, this is liable to happen where the lime originally existed in the form of aragonite.

The magnesian limestones or "dolomites" appear in some cases to be ordinary limestones which have received carbonate of magnesia from the sea after having been deposited.

Massive limestones were generally formed under clear water conditions, and never contain detrital minerals of use to man.

The general characters of the limestones owe their origin largely to the nature of the organisms of which they are composed.

The foraminiferal limestones composed of nummulites enter largely into the formations of the mountain ranges of Southern Europe and Northern India.

In other limestones the shells may be so minute as to be invisible to the naked eye. When they consist of the broken fragments of large crustaceans or of corals their origin is readily recognized.

Pisolitic or oolitic limestones consist of spherical grains of calcareous material arranged in concentric layers. They originate in shallow clear waters, and it seems that layers of lime comprising the oolite grains commenced to be formed round some small fragment such as a grain of sand or shelly material. Although sometimes impregnated with and replaced by valuable minerals, they never contain original valuable minerals.

When limestones are porous they are liable to be impregnated with minerals such as bitumen, and since lime is comparatively soluble, and particularly so in presence of carbonic acid gas, they are frequently entirely reconstituted. Infiltration of magnesian or iron compounds may turn a calcareous lime-

stone into a dolomite or a carbonate of iron and lime rock. Silica replaces limestone with the formation of chert. Ordinary chalk consists of comminuted fragments of sea shells.

Sedimentary Rocks consisting of Volcanic Dust and Ashes.—The ejectamenta from the craters of volcanoes by falling into the sea and accumulating at the bottom may form layers of material known under various names as tuffs, schalsteins, agglomerates, etc. This material consists of fine dust and of scoria or cindery fragments which consolidated in the air from a state of fusion after leaving the volcano.

In addition there is also a certain amount of fragmental material (torn from the sides of the volcano during explosions) consisting of slates, sandstones, etc.

The finer material is spoken of as tuff, and frequently occurs interbedded with other sedimentary rocks or limestones forming tuffaceous muds and sandstones or calcareous tuff.

Isolated crystals of felspar, hornblende and other minerals originating in the igneous rocks are sometimes found embedded in the tuffs or among the scoria.

IGNEOUS ROCKS.

Igneous rocks are composed of silicates which have consolidated from a state of fusion; that is to say, they were once in a highly heated molten condition, like a furnace slag.

Since the igneous rocks, with the exception of those which compose the original crust of the earth, have been squeezed up from molten reservoirs in the interior and injected among the rocks which now constitute the crust of the globe, they are also spoken of as "intrusive rocks."

Although the Archaean, or oldest rocks, are in the main composed of igneous rocks, they have been so sheared and modified by crustal movements since they were consolidated that they are generally classed with the gneisses and schists, *i.e.*, *metamorphic* rocks.

It is important that a general knowledge of the intrusive rocks should be possessed by the prospector, as most of the lodes of the world are more or less intimately connected with igneous rocks, while other mineral deposits owe their origin indirectly to them.

In some cases (*e.g.*, tin and wolfram lodes) the minerals have been directly derived from the igneous rocks during their consolidation from the molten state. It adds to the value of the prospector's report if attention is given to the exact geological conditions under which the mineral deposits are found, and it is impossible to do this without a knowledge of the principal igneous rock types.

Composition.—The igneous rocks vary in composition according to the nature of the molten silicate solutions (or so-called "magmas") which gave rise to them.

The silicates are those of aluminium, iron, calcium, magnesium, sodium and potassium, and in addition they may contain smaller amounts of other substances such as titanium, manganese, phosphorus, lithium, etc.

The so-called *acid* rocks are those containing a high percentage of silica either as free quartz or as combined silica. The *basic* rocks contain a low percentage of silica and a high percentage of bases.

As the molten magma cooled, these substances arranged themselves according to their affinities for one another, with the formation of definite complex silicate minerals which crystallized out successively during the consolidation of the rock.

In completely crystalline rocks, the general order of individualization of the minerals during consolidation is as follows:—First come apatite, zircon, and oxides and sulphides of iron; then olivine, pyroxenes, amphiboles and micas; then felspars and felspathoids, and, finally, quartz and microcline.

In some cases the growth of two of the minerals was simultaneous, so that they interfered with each other's free development.

In classifying the igneous rocks it is usual to do so according to texture and the nature of the minerals composing them. By far the most important rock-forming minerals are the felspars, the ferro-magnesian minerals and quartz. Of the felspars, as seen below, there are several varieties different in chemical composition. Some are silicates of potash and others silicates of soda and lime or mixtures of these. The determination of the kind of felspar not only helps in the

identification of the rock, but gives an idea of its chemical composition. In granite, for instance, the typical felspar is orthoclase, while in gabbro it is labradorite or anorthite. Orthoclase is rarely found in gabbro, while labradorite and anorthite are never found in granite. Similar conditions apply to the ferro-magnesian silicates, while of the other minerals mentioned above some may occasionally occur in such large amounts as to constitute special rock types.

When free quartz occurs, as in acid rocks like granite, it is regarded as being the residual excess of the "siliceous solvent," and although one of the most refractory or infusible of the minerals in rocks, it consolidated last because it was not until the other silicates had separated out as saturated compounds that the quartz was free to solidify.

Structures of Igneous Rocks.—When the rock consolidated slowly it developed a coarsely crystalline texture, so that the minerals of which it is composed can be recognised by the eye.

Where movement has taken place in the rock during its consolidation, the rock is "granulitized" or the crystals may become orientated in the direction of flow.

In pegmatites the structure is that of intergrowth of one mineral with another, such as quartz with felspar.

When the rock cooled quickly it is fine-grained, or, as in some lavas, it may even be glassy.

Porphyritic rocks are those in which separate complete crystals, generally large in comparison with the other minerals, are seen to occur in the main ground mass of the rock. In granite large porphyritic crystals of felspar are often seen set in a coarsely crystalline matrix. In elvan, which is a fine-grained felspathic rock, the presence of separate crystals of quartz and felspar is characteristic, and this rock goes also by the name of "quartz-porphyry."

The ophitic structure is that in which a ferro-magnesian mineral such as augite wraps round and encloses earlier formed crystals of felspar which, under normal conditions, should have crystallized after the augite.

In lavas, the amygdaloid structure is characteristic, while other features of these rocks show by flow lines and parallelism of the crystals that they were in motion while consolidation was going on ("flow-structure").

The amygdaloids were originally steam cavities which at some period subsequent to the consolidation of the rock were filled with such minerals as calcite, quartz, chlorite or other substances deposited from solution.

Brecciated structures are commonly found in volcanic vents. Rocks such as andesites and trachytes, which were originally homogeneous, have had breccia structures developed in them owing to violent shock in the neck of the volcano shortly after intrusion. Infiltration of solutions among the fragments (as in Cripple Creek, Colorado), results in the formation of volcanic breccias worth working for minerals contained in them.

Rock-forming Minerals.—Before describing the rocks the following brief notes have been prepared on the nature of the minerals most commonly found in them. For the determination of these minerals it is customary to make a thin section of the rock, and to examine this through a microscope, when the nature and relationship of the minerals to one another can be readily determined. As a rule the prospector does not possess the means of slicing and examining rocks in this way, and generally determines the kinds of rocks by their general characters, as indicated by the texture and by the more obvious characters of the minerals.

The *felspars* are the most important of the rock-forming minerals. They consist of silicates of alumina, together with silicates of potash, soda or lime, in varying proportions but in some simple ratio. This leads to a classification of the felspars based on their composition; and as the rocks are classified partly on the nature of the felspar they contain, it is interesting to know their general composition.

Orthoclase is a felspar consisting of potassium aluminium silicate, in which sodium, magnesium and calcium may replace some of the potassium.

When perfect it crystallizes in modifications of a flat rhombic oblique prism, belonging to the monoclinic crystal system, and frequently occurs as two crystals united as a twin. The cleavage is rectangular, and the colour varies from white to red; one variety, sanidine, is transparent. Redness is due to the presence of oxide of iron. Adularia is a translucent variety which may possess an opalescent

character, when it is known as "moonstone." "Sunstone" is adularia containing mica scales scattered throughout, giving it a beautiful spangled appearance. Sanidine is a transparent variety common in trachyte.

Microcline is similar in shape and composition to orthoclase. Its chief characteristic is the minute striation on the basal plane owing to a microscopic degree of twinning. Some varieties are pink or greenish.

In volcanic and many hypabyssal rocks the felspar present in the ground-mass is amorphous (non-crystalline) or cryptocrystalline (incipient crystallization).

The plagioclase felspars form a separate group of felspar, comprising varieties under the name of albite, oligoclase, andesine, labradorite, anorthite, and anorthoclase. In composition they vary from pure sodium aluminium silicate (albite) to lime aluminium silicate (anorthite), together with intermediate compounds composed of both of these silicates. Their colours vary from white to green or blue with sometimes a play of colour (*e.g.* labradorite). The soda-lime-aluminium silicate is represented by oligoclase and andesine, while labradorite is a lime-soda-aluminium silicate. Anorthoclase is composed of soda-potash-aluminium silicate.

Oligoclase occurs in lamellar masses with a ready cleavage, while labradorite with its play of colours also occurs in irregular lamellar masses, the faces of the cleavage planes being striated.

In determining the kind of felspar in the rock it is for all practical purposes sufficient to know whether the felspar is orthoclase or plagioclase. Orthoclase is characteristic of the acid rocks, granites, trachytes, and syenites, etc., while plagioclase, distinguished by its basal cleavage and lamellar twining, occurs principally in the basic group—gabbro, diorite, andesite, etc.

The *felspathoids* are the next important group of minerals entering into the composition of certain igneous rocks rich in alkali, and poor in silica. They approximate in composition to the felspars, but are more basic and do not crystallize in the same crystal system.

Nepheline is a hexagonal felspathoid consisting of soda-aluminium silicate similar to anorthite felspar, except that the lime of the latter is replaced by soda.

Leucite is a potash-aluminium-silicate crystallizing in the cubic system. Had there been more silica in the igneous rock, albite would have been formed instead.

Melilite is a lime-aluminium-silicate.

The third important group of rock-forming minerals is that of the ferro-magnesian silicates, including the *pyroxenes* and *amphiboles*, the *micas*, and *olivine*.

The pyroxenes and amphiboles form one large sub-group, the minerals of which are composed of dark-coloured silicates of magnesia, iron and lime, and even soda, in varying proportions. In this group the pyroxenes and amphiboles are sub-groups containing minerals of identical composition, but distinguished from one another by their crystallizing in different forms of the monoclinic system. The most marked difference is that in the pyroxenes the crystal form is a rectangular prism with a nearly rectangular cleavage, while the amphiboles are somewhat lozenge-shaped, and possess perfect cleavages inclined at about 120°. They also occur as slender fibres sometimes closely packed together, and when very fine it is known as asbestos.* The difference between the pyroxenes and amphiboles is not in composition, as each group has corresponding minerals in the other, but in their mode of crystallization; the general facts may be summed up by saying, that if an amphibole is fused it generally consolidates as pyroxene, while if the rock is altered by certain outside agencies, the pyroxene may change to amphibole ("*Uralitization*").

Some members of the pyroxene (*e.g.* enstatite) and the amphibole (*e.g.* anthophyllite) groups are distinguished from the foregoing by crystallizing in the rhombic system. Diopside is a pale pyroxene consisting of lime-magnesium-silicate, and corresponding with actinolite in the amphiboles. Augite (pyroxene) is a black or greenish lime-iron-magnesium-aluminium-silicate, corresponding with hornblende (amphibole).

For practical purposes it is only necessary to distinguish the augite and hornblende.

Several minerals belonging to the hornblende series are:—hornblende, tremolite, and actinolite. Hornblende occurs as

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* Not to be confused with the Canadian "asbestos" or chrysotile derived rom serpentine rocks and of a quality altogether inferior to the true asbestos.

black or greenish-black lozenge shaped crystals with the characteristic cleavage already described. Tremolite is found in long crystals of white or grey colour. Actinolite is generally greenish in colour and occurs in slender prisms. In the augite group the minerals augite, diopside, diallage, enstatite, bronzite, spodumene, and wollastonite may be mentioned, some of them belonging to the *Rhombic* and others to the *Monoclinic* divisions. Augite is black or greenish black with high lustre and occurs in short stout prisms with the characteristic cleavage above mentioned. In igneous rocks it is often found converted to hornblende (uralitized). Diopside is a grey-green or greenish white variety of augite. Diallage is found in gabbros and serpentines and occurs as grey or green irregular lamellar masses. Enstatite is similar in composition to augite but crystallises in the rhombic system in forms similar to that of augite. Bronzite is a ferruginous variety of enstatite with a bronze or pearl lustre, containing up to 12 per cent. of iron. Spodumene is a greenish or greyish pyroxene which occurs as large crystals with perfect cleavage and irregular fracture. Wollastonite is a silicate of lime occurring as cleavable masses with fibrous interlacing or columnar structure. In colour it varies from white to grey, yellow or brownish.

The Micas.—The perfect basal cleavage enabling the mineral to be split into infinitely thin flakes is the characteristic property of the micas. They consist of potash, lithia and soda, alumina, iron, magnesia and silica. There are two groups. All occur in six-sided prisms.

Biotite is a dark brown (rarely green) mica consisting of iron-magnesium-potassium-aluminium-silicate. Muscovite is a translucent, light yellowish, greenish or brown mineral consisting of potassium-aluminium-silicate.

Lepidolite is a variety of muscovite occurring in small scaly aggregates, generally of a pinkish tint, and consisting of silica, alumina, potash and lithia, with manganese and small amounts of rarer elements. The mineral gives a red colour to the blow-pipe flame.

Olivine is a mono-silicate of iron and magnesia occurring in intermediate and basic rocks. It is of a green to brown colour and usually occurs as rounded or irregular grains.

Epidote is an aluminium lime silicate with varying proportions of iron and manganese oxides.

Another mineral entering largely into the composition of certain basic igneous rocks is magnetite, which sometimes occurs so plentifully as to make the igneous rock an iron ore.

As accessory minerals which may be present may be mentioned garnet, apatite, monazite, sphene, zircon, etc.

Distribution of the Minerals in Rocks.—Each of the rock-forming minerals above described has a more or less limited range of occurrence in the igneous rock series, and shows marked preferences for certain types of which it is consequently characteristic.

Quartz occurs as an essential constituent only in the acid rocks, or more acid of the intermediate rocks (granites and syenites).

Orthoclase has a somewhat greater range, and is found abundant in the acid and intermediate rocks. Albite occurs in small amounts in the granites and syenites. Oligoclase occurs as an unimportant constituent of granite, but ranges from syenites to gabbros.

Labradorite ranges from the diorites to the gabbros.

Anorthite is mainly confined to the basic division.

Of the ferro-magnesian minerals augite is found principally in the rocks, ranging from diorites to the ultra-basic rocks. Hornblende may occur in all the rocks from granite to gabbro, but is principally found in the syenites and gabbros. Biotite is mainly developed in the granites and syenites, while muscovite is characteristic of the acid rocks. Olivine occurs mainly in gabbro and the ultra-basic rocks, while oxides of iron are found in the intermediate, basic and ultra-basic rocks.

Classification of Igneous Rocks.—From what has already been said it may be inferred that the igneous rocks are capable of being classified according to their ultimate chemical composition, the nature of the minerals of which they consist and their texture. But while well-defined types can be arranged in groups, there are nevertheless transition types between any two groups which share the characters of both. The following table contains the principal igneous rock types likely to concern the prospector. Many of their varieties go by fanciful names, depending on some unusual

features of the rock, but they can generally be classified under the main rock types:—

	PLUTONIC.	HYPABYSSAL	VOLCANIC	
	(Deep - seated, coarsely crystalline).	Rocks intermediate in structure between plutonic and volcanic types. Generally fine-grained, but coarser in basic varieties. Occurring as dykes, and are usually porphyritic.	Finely crystalline	Glassy.
ACID.	*Granite.*	*Quartz-porphyry.*	*Rhyolite.* (Variety:—Anorthoclase-rhyolite.)	*Obsidian* (Pitchstone).
	Typically:—Orthoclase; Biotite (or Hornblende or Augite) and Quartz. Albite or Oligoclase may also be present			
Rocks INTERMEDIATE in composition between the Acid and the Basic rocks.	*Syenite.*	*Syenite-porphyry.*	*Trachyte.*	*Trachyte glass*
	Typically:—Orthoclase (variety Sanidine in Volcanics); Biotite (or Hornblende or Augite); no Quartz. Albite or Oligoclase may be present.			
	(*Nepheline-Syenite*).	*Tinguaite.*	*Phonolite.*	
	Typically:—Same, but containing Felspathoids in addition.			
	Diorite (Tonalite) (Quartz-diorite.)	*Diorite-porphyry* (Porphyrite).	*Andesite* (Quartz-Andesite or Dacite). (alters to Propylite.)	*Andesite glass.*
	Typically:—Plagioclase (Oligoclase, Andesine); Biotite or Hornblende and accessory Quartz and Augite and in one variety there is Nepheline (Theralite or Nephdiorite). Enstatite in varieties low in iron.			
BASIC	*Gabbro* (Epidiorite).	*Dolerite* (and Diebase).	*Basalt. Melaphyre.*	*Tachylite* (very rare). *Variolite* (devitrified).
	Typically:—Plagioclase (Labradorite to anorthite): e Pyroxene, and (1) with or (2) without Olivine. Mica-traps come in the basalt group. Many "greenstones" are altered diabases in which Augite is altered to Hornblende, and where there has been chloritization and serpentinization. Basalt with Felspathoid to exclusion of Felspar is Tephrite (no Olivine) and Basanite (Olivine present).			
ULTRA-BASIC.	*Peridotite* (and Serpentine).	*Picrite.*	*Limburgite.*	
	Typically:—Augite (Bronzite and Hypersthene) or Hornblende and occasionally Biotite: Olivine.			

In the identification of an igneous rock the general tint and texture and relations of minerals to one another should first be noted. The next point is to determine whether the felspar belongs to the orthoclase or to the plagioclase group. The next point is the presence or absence of quartz as an essential or occasional constituent, and finally what is the dominant ferro-magnesian silicate; and is olivine or a felspathoid present. The basic rocks are dark coloured, since they owe their tint to the considerable proportion of ferro-magnesian silicate they contain. Many of these rocks have well-marked and characteristic alteration types, while examination of their weathered surfaces often affords a clue to their nature.

General Remarks on Igneous Rock-masses.—The intrusive rocks occur either as bulky masses in the form of batholiths and laccolites, or else as sheet-like intrusions such as dykes. The form which the intrusion takes is dependent upon the structure of the rocks among which it is intruded; upon the fluidity or viscosity of the magma at the time of the intrusion; upon the bulk of igneous material intruded, and probably also on the force with which the intrusion was accompanied. The magmas from which the basic rocks are derived were more fluid (and more readily fusible) than the acid magmas, so that basic rocks more frequently occur in sheet-like or dyke forms than the acid rocks. Where the rocks occur in bulky masses they are always coarsely crystalline owing to the slow rate at which they have cooled. The dyke or "trap" rocks, on the other hand, are more finely grained and contain, as a rule, porphyritic crystals, which have sometimes developed prior to the intrusion of the rock, in which cases they may be corroded by reaction of the magma upon them by relief of pressure on intrusion. By taking notice of all the characteristics of the rock its history can be ascertained, and to the prospector this is of importance since many igneous rocks are closely connected with ore deposits and with rare minerals.

As illustrating the form or shape of igneous masses, granite may be stated to occur always as bulky intrusions, and although now exposed at the surface in many parts of the world, was originally a deep-seated rock which has been revealed by denudation or wearing away of the rocks which covered it.

The dykes (elvans, quartz-porphyry, felsite, etc.) which are commonly associated with granite intrusions, are of identical composition but fine-grained owing to their having been injected into fissures after the granite had for the most part consolidated. Some rocks, as in the case of andesites and trachytes, are seen in the necks of volcanoes to be shattered and comminuted so that they are spoken of as volcanic breccias.

Gabbro is another example of a coarsely crystalline rock generally occurring as bulky intrusions, but, as the table shows, it has its finer grained representatives of dyke form.

Of the volcanic rocks or lavas little need be said. The acid volcanic rocks, such as rhyolites, are light coloured, very fine grained or glassy, while the basic volcanics are dark and sometimes fairly crystalline, as with basalts, or present ropey or pillow form (spilites). To illustrate the interest which even a lava flow may have for the prospector, the plateaux capped with Tertiary basalts in Victoria may be referred to. Although these basalts were originally poured out on to a plane traversed by river valleys, they now form the highest points of the district owing to their resistant nature enabling them to withstand the physical forces of disintegration which have worn away the surrounding district. The gravels of the old river valleys buried below these basalts are auriferous, and have yielded great quantities of alluvial gold.

Coarsely Crystalline Rocks.

Granite consists of white or pinkish felspar, mica and quartz. The felspar is usually orthoclase (sometimes microcline), but occasionally plagioclase (albite or oligoclase) may be present and in soda-granites are in excess. In place of mica there may be hornblende or even augite. There are many modifications of granite. *Tourmaline granite*, for instance, contains tourmaline in place of mica. In the extreme modification of tourmaline granite it consists of tourmaline (or schorl) and quartz, when it is known as "*schorl rock*." It may be briefly remarked that schorl rock is granite altered by vapours containing boric acid and other substances emanated from the granite as it consolidated. These vapours attacking the biotite of granite converted it into brown tourmaline, and the felspar

was converted into blue tourmaline and quartz. A modification of granite owing its origin to the same kind of action is *Greisen*. In this case, however, the vapours contained principally fluorine, lithia, and other compounds, which, reacting on the granite, converted felspar into topaz, mica and quartz. The *china-clay granite* is another type owing its origin to similar actions in which felspar has broken down to kaolin and quartz.

Pegmatite is a coarse or "giant" granite, generally occurring in the form of veins associated with large granite intrusions. In it the felspar and quartz have intergrown with one another by simultaneous crystallization. Pegmatites often contain rare minerals. The grey and red granites owe their colours to those of the respective felspars.

Syenite consists of pinkish orthoclase with some plagioclase (albite or oligoclase) and hornblende. Quartz is absent except as an accessory constituent. Zircon occurs occasionally in important amounts. The syenites form a group of rocks going under different appellations according to the kind of ferro-magnesian mineral present, and to the kind of felspar. *Monzonite*, for instance, is augite-syenite containing also hornblende and biotite. *Laurvikite* is an augite-syenite with biotite and anorthoclase. When it contains a large amount of soda, one of the felspathoids is formed, and we get such modifications as *nepheline-syenite*. This group passes into diorites with increase of the plagioclase felspars, or into theralites with nepheline.

Diorites in general outward appearance resemble grey granites, and consist typically of plagioclase (albite or oligoclase) and hornblende with accessory augite, but quartz and orthoclase may be present, and indeed quartz may form an essential constituent of the acid diorites, which are practically lime-soda granites. Like the syenites, they are divided according to the nature of the principal ferro-magnesian mineral. *Tonalite* is a quartz-mica-diorite, while *Napoleonite* is diorite with an orbicular structure. The diorites pass insensibly into the gabbro group, when they contain much augite. When the iron percentage is low enstatite may occur instead of augite. *Essenite* is an augite diorite containing olivine and so is intermediate between gabbro and theralites.

Gabbro.—Magmas rich in iron, lime and magnesia, tend to form olivine and pyroxenes on consolidation. The gabbro consists of plagioclase (labradorite and anorthite), and a pyroxene—generally diallage. Accessory quartz may be present in the more acid varieties, but in the basic varieties olivine forms an essential constituent of certain types.

Norite is a type of gabbro containing hypersthene in place of augite or diallage.

Theralite is a nepheline-bearing gabbro of rare occurrence.

Troctolite or *Forellenstein* is gabbro consisting only of anorthite and olivine.

When the felspathic constituent fails in the gabbro it passes into the basic rock *pyroxenite*, or if olivine is present into the *peridotites.*

Dunite is a serpentinized aggregate of olivine and chromite. The *Diabases* are hypabyssal representatives of the gabbro, but in their ophitic structure and finer grain they differ from them.

Pyroxenites and Peridotite.—These rocks contain but little silica. The pyroxenites are often found as local variations of gabbro. The peridotites are pyroxenites rich in olivine, but containing no felspar. Where the peridotite consists of olivine with chromite it is called *Dunite.* Some of the basic rocks are very rich in magnetite. The peridotites and other rocks rich in olivine are liable to become altered to serpentine.

Serpentine.—This change in olivine-bearing rocks is due to decomposition in the olivine itself. In this process magnetite and serpentine stained with iron are formed in the network of cracks which develop in the olivine crystal during the change owing to the expansion of the substances involved. Serpentine, soapstone, and other decomposition products of the ferromagnesian minerals are also formed from enstatite, bronzite, hypersthene and other silicates rich in iron and magnesium but poor in alumina.

Finer-grained and Porphyritic Rocks.

Typically these rocks are the dyke representatives of the coarse-grained rocks just described.

Quartz-Porphyry consists of a micro-crystalline ground mass of orthoclase and quartz in which are set isolated crystals of quartz and felspar, giving the rocks the character of a porphyry. The quartz is in hexagonal crystals terminated by basal pyramids, but these crystals are often corroded by re-absorption of quartz into the magma. It is also known as quartz felsite. The rock sometimes resembles a fine-grained granite, when it is called micro-granite. Granophyre is a variety in which quartz is intergrown with the felspar and is really a micro-pegmatite. The quartz-porphyries occur as dykes generally in the vicinity of granite, to which they are similar in composition. They are not unfrequently associated with ore deposits.

Syenite-Porphyry.—Dyke representatives of the syenites. The main mass of the rock is fine-grained felspar, but throughout there occur isolated crystals (phenocrysts) of biotite or hornblende. The nepheline syenites are represented in the dykes by the *Tinguaites*, *Bostonites*, etc., in which the felspar is largely anorthoclase, and occurs as isolated lath-shaped crystals.

Diorite-Porphyrite or "Porphyrite."—Similar in composition to the diorites and representing their finer hypabyssal type. A fine-grained ground-mass containing separate crystals (phenocrysts) of plagioclase with biotite or hornblende. Quartz frequently occurs as accessory crystals or as a cement to felspar, and such rocks are commercially known as granites.

Basalt.—Dark brown volcanic and hypabyssal rocks consisting of plagioclase and augite; magnetite and olivine are important accessory constituents. Their tendency to columnar jointing is a marked characteristic. When the rock is coarsely crystalline it is a *dolerite*, and this may be granitoid or it may contain porphyritic crystals of augite, felspar or olivine. Dolerites of pre-Tertiary age are known as diabase. *Melaphyre* is altered, generally ancient, olivine-basalt. The Tephrites and Basanites are Leucite and Nepheline Basalts without and with olivine respectively.

Mica-Traps (Lamprophyres).—These occur as dykes of fine grain, and consist of biotite, which may be altered to chlorite or rutile; and of augite, which may be altered to hornblende, The felspars are of the alkali and lime-soda groups.

The felspar occurs principally in the ground-mass. The sub-classes of this group are dependent on the nature of the felspar. *Minette* contains orthoclase and mica. *Kersantite* contains plagioclase and much mica. *Camptonite* is a lamprophyre containing plagioclase and hornblende, but no essential mica. *Vogesite* is an orthoclase hornblende rock.

An ultra-basic type is *Monchiquite*, which has a glassy ground-mass containing small crystals of hornblende and phenocrysts of olivine, augite and hornblende.

As a group they are characterized by low amount of silica and high percentage of potash. The minettes and kersantites occur as dyke modifications in connection with granite, while the camptonites and monchiquites occur with nepheline-syenites.

Limburgites.—A fine-grained rock containing no felspar, but consisting of augite, olivine crystals, and iron ores set in dark glassy matrix. *Augitite* is a variety containing no olivine, but consisting of augite and magnetite crystals which have separated out from the magma at two different times during the history of its consolidation.

Volcanic Rocks.

These rocks have consolidated rapidly at the surface, with the result that their textures are in strong contrast to the plutonic rocks, but they show features linking them with the hypabyssal types. Many of them are glassy, while most of them contain porphyritic crystals. In contrast to the micro-pegmatitic or granophyric structure, the ground mass of lavas is frequently glassy (vitrophyric), but in this glass there may be smaller porphyritic crystals which were formed during the consolidation of the rock at surface. In the necks of volcanoes the rocks are often exceedingly brecciated and broken, owing to explosive shocks after the consolidation of the igneous plug.

Rhyolite.—Crypto-crystalline to glassy rocks similar in composition to granite. They often contain quartz crystals and clear felspar (sanidine). The flow structure is a characteristic. They are very similar to the quartz-porphyries or

felsites. The obsidians are completely glassy rocks which contain spherulites or incipient crystals. A sub-group is distinguished by anorthoclase felspar instead of sanidine, and is known as soda or anorthoclase rhyolite or ceratophyre.

Trachyte.—In composition the trachytes are similar to the syenites, but they are fine-grained owing to their having consolidated at surface. The ground-mass is felspathic, and contains separate crystals of orthoclase or sanidine, and sometimes plagioclase, together with hornblende, biotite or augite scattered throughout. The crystals are generally parallel, due to the flow in the rock prior to consolidation.

Phonolite (Clinkstone).—This rock is the volcanic equivalent of nepheline-syenite, and consequently is rich in soda. It may be described as nepheline-trachyte. The phonolites are porphyritic rocks with a completely crystalline matrix consisting of sanidine and nepheline, in which occur isolated crystals of orthoclase, nepheline, and pyroxene (ægirine). Leucite is also present in one sub-group (leucitophyres) and may occur with or without nepheline. If with, it is called leucite-phonolite. They are dark grey rocks in which sanidine crystals are clearly visible to the eye. The pyroxene crystals are as a rule too small for detection except by the microscope. The phonolites are readily decomposed. The rhomb-porphyries of the Christiania basin, containing lozenge-shaped potash-soda-felspar, often corroded, fall into this group.

Andesite.—A porphyritic rock consisting of a ground-mass of felspar, in which are embedded crystals of plagioclase (labradorite or andesine), together with biotite, or hornblende and sometimes augite. Andesites are very common lavas. *Dacite* is a quartz-andesite, and but for the fact that the felspar is plagioclase, and not orthoclase, it may be said to resemble quartz-felsite. When the minerals of the coarser andesites are altered to chlorite, epidote, kaolin, and other substances, the rock is known as propylite.

Variolite is a basaltic glass containing abundant microlites of felspar in sheaf-like groupings situated close together. Tachylite is a glassy basalt. Both occur as chilled margins to dolerites.

ALTERED AND METAMORPHIC ROCKS.

Rocks, both sedimentary and igneous, are capable of profound modification or alteration by various causes, and the older the rock is the less likely is it to have escaped these altering actions. Some of the oldest rocks are so thoroughly reconstructed and modified both in composition and in structure, as to make it a matter for speculation as to what they originally were. The changes which have gone on in the different kinds of rocks form a wide field for investigation, and it is impossible here to deal in any thorough manner with these changes without subordinating our object to be useful to that of giving an excess of detail. It is of use to know, however, something of the general changes which have taken place in the older and even in some of the newer rocks.

It has already been pointed out how important rock types such as greisen, schorl rock, serpentine, propylite and other igneous rocks may be formed by the actual breaking down of some minerals and the building up of others through the means of active gases and solutions, but there are other modes of alteration affecting rock masses in which the rocks are either deformed or are altered in mineral composition without the addition or subtraction of material.

Rocks may be altered in three ways by actions classified under the following heads:—

Thermal metamorphism (alteration).
Dynamic metamorphism.
Metasomatism.

Some rocks show that they have been affected by all three actions. Igneous rocks are, of course, not affected to the same extent by thermal metamorphism alone as sedimentary rocks.

Thermal Metamorphism.

Thermal metamorphism is the change in rocks (principally noticeable in sedimentary rocks) effected by heat, and as the change has, as a rule, been brought about by the heat given off from intrusive igneous masses, the action is generally spoken of as contact metamorphism.

The most intense contact metamorphism is that which has taken place in the sedimentary rocks in contact with plutonic or deep-seated intrusive rocks, but thermal metamorphism is

to greater or less degree characteristic of the rocks adjacent to intrusive igneous rocks of all kinds, whether plutonic or volcanic. The nature of the alteration depends upon the intensity of the heat and upon the composition of the rock.

As the intensity of the heat which was given off by an igneous rock after intrusion must have varied inversely as the distance from it, it follows that the sedimentary rocks in its immediate vicinity must have been altered much more intensely than those more distant, with the result that rocks of uniform composition show a mineral development different near the igneous rock from that at a distance.

In the case of the contact metamorphism round the Cornish granites it is roughly estimated that the alteration in the sedimentary rocks has extended to a distance of three-quarters to one mile from the granite. Near the Cornish granites the silts and shales have been changed to mica-schist. Further from the granite the silicate of alumina compound andalusite has been developed. Further still, there is spotting indicating incipient crystallization in the slates, beyond which the thermal effect dies away.

Quartzose sandstones, owing to their refractory nature, are altered only by intense metamorphism. They may be so intensely affected as to be partially fused and turned into quartzites. If other substances are present certain fresh minerals are developed, as, for instance, diopside, which is formed from argillaceous and calcareous material. In impure clayey sandstones, garnet, mica, and other minerals are developed, and the rock may become very coarse in texture. In argillaceous rocks, brown mica with spots and knots of chiastolite are developed by thermal metamorphism which is not too intense. By more intense metamorphism the chiastolite crystals are broken down and the whole of the rock becomes converted to quartz and mica with the production of mica-schist. Spotting by the development of such minerals as mica, chlorite, chiastolite, etc., is one of the most obvious characteristics of contact-altered argillaceous rocks. With intense metamorphism this spotting is lost and the rocks are changed to hornstones. Cordierite, corundum, etc., are also developed.

More or less pure limestones are recrystallized, with the formation of marble, by contact metamorphism.

Many limestones contain other materials such as dolomite, clay, silica, and ferruginous substances which under conditions of contact metamorphism are capable of forming new lime-bearing materials. Fibrous hornblende such as actinolite is a common product, while wollastonite, diopside, augite, felspar, and other silicates are formed by contact of impure lime rocks with plutonic intrusives. Argillaceous limestones by loss of carbonic acid gas become converted to "calc-flinta" or "calc-hornfels" (silicate of lime) which is a tough, splintery (porcellanous) rock. Such rocks are found, for instance, in the metamorphic zones of the Cornish granites. Garnet is also a common mineral in altered argillaceous magnesian-limestones.

The more acid intrusive rocks are but little affected by contact with other newer igneous intrusives owing to their refractory nature, but they may be decomposed in various ways. The basic rocks, on the other hand, are generally easily affected. Thus hornblende rocks give rise to chloritic products and to biotite. Augite is converted to hornblende or biotite. The felspars also are liable to reconstruction or of change to micaceous substances. Epidote is a common alteration product of the lime-bearing compounds, while free calcite is common in altered basic rocks. Diopside and augite may also be secondary products.

Dynamic Metamorphism.

By dynamic metamorphism is meant an alteration produced in rocks by mechanical forces such as those brought into play by earth movements during which the rocks may be folded, over-thrust, and cleaved. The heat developed by internal friction during such movements is also an important factor. The most obvious effect of these actions is the contortion or folding of the rocks accompanied in the softer rocks by development of a cleavage which crosses the general bedding. The explanation of this is, that although the cleavage may be parallel with the actual planes of bedding, it is only because the beds were squeezed into a series of sharp folds or waves before the cleavage was developed. Harder bands in the rocks which have been cleaved are merely bent and broken, and the softer argillaceous material appears to have flowed round the parts of the broken harder bands (mylonite), with the

production of so-called "eyes." Crush or friction conglomerates owe their origin to this kind of action.

Development of mica along the cleavage planes is common in cleaved felspathic rocks; while such minerals as tremolite and chlorite may also be formed, depending on the composition of the rock affected.

The effects of dynamic metamorphism, when accompanied by development of heat, may be extreme.

The ancient regional schists and gneisses occupying such comparatively large tracts in some districts owe their origin largely to the action of dynamic forces on both sedimentary and intrusive rocks.

The schists form a group of profoundly altered rocks, known as mica-schist, hornblende-schist, garnetiferous-schist, etc., while the gneisses are coarser rocks having a roughly foliated structure in which the original minerals are crushed or drawn out into lenticles. The oldest known rocks are schists and gneisses, generally resulting from the deformation and reconstruction of igneous rocks, in which the plutonic or completely crystalline group are largely represented in the gneissic division.

Metamorphic Rock Types.

Granulites and Eclogites.—These are crystalline rocks occurring in association with gneisses. They are probably highly altered igneous rocks.

Acid granulite consists of orthoclase, quartz, garnet, and mica. Other minerals such as kyanite are also present.

Pyroxene granulite consists of plagioclase, quartz, augite and hypersthene, hornblende and magnetite. These rocks have a "granulitic" structure.

Eclogites are crystalline rocks consisting of red garnet, augite, quartz, hornblende, and kyanite.

Schists.—The schists form a group of metamorphic rocks having a foliated or schistose structure. They consist of flattened grains of felspar or quartz together with mica, hornblende, chlorite, and talc. Unusual types occur, such as itabarite, composed of hæmatite and quartz. Some of the schists are further characterised by the presence of special minerals such as cordierite, kyanite, graphite, garnet, tourmaline, etc.

Gneisses.—Derived from plutonic rocks by dynamic metamorphism. According to the minerals present they are known as hornblende-gneiss, mica-gneiss, etc.

Slate.—Argillaceous rocks with a cleavage produced by pressure. When altered by contact they develop spots and knots of andalusite and other minerals.

Hornfels.—Fine-grained, crystalline, contact-altered rocks consisting of quartz, chlorite, mica, and ferruginous material.

Metasomatism.

This means a change in the composition of a rock by the addition or withdrawal of certain substances from it. This is generally effected by underground waters containing substances in solution. Weathering action is modified metasomatism. In some cases material is merely deposited in interstitial spaces, between the grains of which the rock is composed. This is known as cementation. Many quartzites are quartzose sandstones cemented by siliceous materials. Limestones afford some of the finest examples of metasomatism. Limestone is comparatively soluble, and particularly so in waters containing carbonic acid, so that it is particularly liable to be replaced by such compounds as dolomite, silica, and carbonate of iron.

By weathering actions felspars are decomposed. The alkalis of felspars are carried away as carbonates, and clay is left in the cavity formerly occupied by the crystal.

The ferro-magnesian silicates are rotted in the same way by the change of the calcareous constituents of the mineral to carbonate with liberation of silica, kaolin, and iron oxide.

Typical metasomatic actions are those connected with the alteration in the country rock in the vicinity of lodes. Such actions are classified under such terms as silicification, carbonation, hydration, topazisation, tourmalinisation, etc.

MINERAL DEPOSITS.

By DONALD A. MacALISTER, Assoc. R.S.M., F.G.S.

ORE DEPOSITS.

The mode of occurrence of the useful minerals constitutes a special branch of geology, which has in late years been so systematised that it is now possible for mineral deposits to be grouped or classified according to their origin, thus enabling the expert to form opinions on their value.

It is in the occurrence of metals or metalliferous minerals that the prospector is mainly interested, so that the following notes, though far from complete, should be useful. In a brief account, however, it is difficult to determine the best mode of treatment of the subject so that both the nature and the origin of the deposits may be indicated, and yet to group all minerals of a kind under the same heading.

In describing the different kinds of ore deposits it is best to adhere to the modern methods of grouping them according to the various genetic types as are represented by such terms as *detrital*, *pneumatolytic*, *hydatogenetic*, *segregation*, *replacement*, etc.

After the pronunciation of these words has been mastered they will be found to be of considerable use to the prospector in enabling him to draw analogies between any new finds and well-known types of ores of similar origin as described under the respective headings.

The terms *syngenetic* and *epigenetic* under which all deposits may be grouped are explained in the glossary.

Detrital Deposits.—A type of mineral occurrence of importance to the prospector is that in which the minerals such as gold, platinum, monazite sands, tin-stone, wolfram, magnetite, titaniferous iron ore and precious stones are found, as

fragments in detrital or alluvial material of rivers, upland lakes or drainage basins and sea beaches. The only conditions essential for the formation of such deposits are that there must have been an original source from which the heavier resistant minerals such as those mentioned were derived, and that they have been sorted and concentrated by running water.

In many stratified deposits minute quantities of the minerals mentioned occur, but it requires the vigorous sorting action of natural running water to concentrate them into workable deposits.

Examples of alluvial deposits are, first and foremost, the gold in the gravels of California, Klondyke, West Australia, Victoria, New Zealand, and the Urals. In these the gold occurs either among a thin layer of sands and gravels or in a stratum buried below several beds of sandy, gravelly, or conglomeratic material in river-beds. In some of the deposits, particularly in lakes, the mineral may be found in one of the intermediate layers. In some of the older river terraces or old dried up river-ways gold has been found, as in New Zealand.

Remarkable instances are known of the occurrence of alluvial gold in the beds of river-channels of Pliocene age filled up with basalt through which shafts must be sunk to reach the deposit. As an instance of this may be mentioned tbe New South Wales and Victorian old alluvial or "deep lead" deposits which occur near the top of basalt-capped hills. The extensive denudation which the country near these deposits has suffered since the filling up of the old valley with basalt, has not affected to the same extent the hard basaltic cap which protects the auriferous gravels below it.

The gold in the beach sands of Cape Nome (Alaska), Australia, and New Zealand affords examples of auriferous marine detrital deposits, while the monazite sands of Brazil, from which most of the thorium of commerce is obtained, is an example of a sea-beach deposit of economic value.

In these alluvial deposits the gold occurs in fragments varying in size from minute specks up to large nuggets or rounded fragments, and is commonly associated with other heavy minerals.

The occurrence of gold in Glacial boulder-clay in British Columbia should also be mentioned.

Platinum has not so wide a range as gold and occurs principally in alluvial deposits in the Urals; but it has also

been found in California, Brazil, British Columbia, and other places in workable deposits.

Large amounts of titaniferous iron sands occur in Chili, Canada, and other places in sea-beaches. Tin-stone occurs in enormous quantities as alluvial deposits in all parts of the world where tin-stone is found. The deposits in Malay are the most noteworthy; but alluvial tin-ore also occurs in Bolivia, Dutch East Indies, Australia, Tasmania, Siam, and Cornwall. In Cornwall the ore occurs in shallow upland basins of erosion and in streams draining them.

Lodes.—The most important metalliferous deposits of the world are those which occur as the infilling of fissures, cracks, crush-zones or other spaces formed by the disturbance and fracturing of the solid rocks. Such deposits are termed veins or lodes. Where the rock in the district in which a lode occurs is exposed at surface, the "outcrop" or upper part of the lode can be readily recognised by the hard quartzose veinstone, the ferruginous staining of the rock, or the staining by other oxidised substances such as copper, manganese, etc.

When the lode is followed downwards by means of a shaft it is found that this oxidised zone is generally confined to the upper part of the lode, that is to say, the part of the lode to which oxygenated surface waters have had access, and by which the minerals in the lodes have been oxidised, turned into soluble compounds, and carried down the lode and re-precipitated at lower levels. In this zone a great variety of secondarily deposited minerals occur, such as native copper, silver and gold, oxides and sulphides of silver, copper and iron; sulphates and carbonates of lead and zinc; silicates, chlorides, and many other compounds ranging from simple to exceedingly complex minerals. Some of the best examples of secondary deposits in the world are those of the desert of Atacama and other places in Chili. With secondary compounds there often occur unaltered original minerals, such as tinstone, which remain unaffected under these conditions.

Below this zone the minerals of the lodes consist of unaltered substances existing in the condition in which they were when first deposited. The most important of the minerals of the unaltered parts of the lodes are the sulphides

together with a few stable oxides such as tinstone and wolfram. In lodes, then, the deposition of the ores takes place in two ways: (1) minerals deposited directly from solutions coming from some deep-seated source, and (2) minerals which after deposition have undergone secondary changes, with reconcentration, generally by the action of meteoric waters percolating through the lodes, but occasionally by the thermal effects of contact with heated igneous masses intruded after the deposition of the ores. A knowledge of the character of the ores from this point of view is important since it bears on the question of zones of enrichment and permanence in depth.

Broadly speaking, most lodes may be briefly referred to as *sulphidic* or *oxidic.* In the sulphidic group the ores consist of sulphides of one or more of the metals such as copper, lead, zinc, mercury, etc., or they may consist of small quantities of the rarer metals such as gold, silver, etc., mixed with baser sulphides.

In the oxidic group the ores consist of originally deposited oxides such as tinstone, wolfram, certain nickel ores with iron and manganese.

Both classes of ores, the sulphidic and the oxidic, can be classified according to the conditions under which they were concentrated, but for the sake of brevity they will be described together under the following modes of origin.

Lode Structures.—The forms and structures of lodes are due to the form of the original cavity in which the metalliferous minerals were deposited. In simple fractures the ores occur as simple infillings of the fissures or may show banded arrangements owing to intermittent formation of the veinstones. Where the rock is shattered or traversed by numerous fissures filled with mineral the body is known as a stockwork. In many cases the ores are deposited in shear zones and breccias of great width, and as the minerals are deposited among the fragmental material of such lodes the structure has a corresponding nature. Instances of these structures are numerous and are connected not only with shear and crush zones, but with volcanic tuffs and breccias. More massive lode forms are produced in some rocks, such as limestones, by replacement of parts of the country rock by metalliferous minerals, of which galena and iron ores may be particularly mentioned. Massive

or irregular forms of deposits are also found at the contacts of dissimilar rocks.

The so-called gash-veins are confined to limestones. The gash-vein is merely a vein occurring in a limestone and in comparison with its thickness is usually somewhat limited in depth and length. They are typically developed in joints and bedding planes of limestones, and are terminated above and below by the sandstones or shales of adjacent beds. They generally contain galena or zinc blende, but may contain iron ores, etc. Unless the gash-veins are of great size the mining of them is somewhat speculative.

Origin and Nature of Lodes.—Most metalliferous deposits are derived more or less directly from igneous rocks. The conditions under which lodes can be formed are various, but are broadly divisible into three well-marked groups depending on their origin. The various modes of origin are referred to under the terms:—

(1) *Pneumatolysis.*—Deposition of minerals from superheated gaseous compounds derived from deep-seated intrusive rocks during their consolidation.

(2) *Hydatogenesis.*—Deposition of minerals from watery solutions more or less directly derived from igneous rocks but under moderately cool conditions.

(3) *Metasomasis.*—Deposition of ores through chemical reaction of solution or gases on the country rock accompanied by its replacement partly or wholly by ores.

The lodes formed under *pneumatolytic* conditions show well-marked features distinguishing them from other types. They all occur in the vicinity of plutonic or coarse-grained igneous rocks, from which they were derived in the form of vapours; and generally they were formed at considerable depths shortly after the intrusion of these rocks, and consequently under conditions of high temperature and pressure. Such deposits are generally of considerable geological age, since from their deep-seated origin a long period of time has elapsed between their formation and their exposure at surface through the extensive denudation of the overlying rocks.

Certain classes of ores are always connected with certain igneous rocks, so that the presence of the one is frequently a

sign of the presence of the other. Thus, the ores connected with granites comprise the oxidic ores of tin and wolfram and the sulphidic ores of copper, arsenic, zinc, and other metals. With these ores are associated other minerals which further characterise deposits of pneumatolytic origin. The minerals which may be found with these ores are quartz (characteristic of most lodes of whatever origin), tourmaline, axinite, topaz, fluorspar, iron pyrites, and a few less common minerals. Accessory ores are those of uranium, antimony, silver, lead, cobalt, and nickel, and occasionally molybdenum. The association of the ores with such minerals as topaz and fluorspar is explained by the manner in which the metals were concentrated in the fissures. It is believed that the metals were diffused in minute quantities throughout the granite magma before its consolidation, and that during its consolidation the metals were extracted from it in the form of fluorides by vapours containing fluorine, boron, sulphur, and steam. On entering the cooler parts of the fissures or crush zones the metals were deposited as oxides or sulphides, while the fluorine, boron, and sulphur reacted on material of the country rock with formation of rocks containing tourmaline, axinite, topaz, pale mica, fluorspar, and other minerals (greisen, schorl rock, propylite, etc.).

Lodes of pneumatolytic origin are also found connected with large masses of gabbro, but their importance is insignificant when compared with the above. In this case the principal "carrier" appears to be chlorine (and not fluorine) while the minerals carried into the fissures are phosphoric acid and rutile.

The greater number of lodes belong to the *hydatogenetic* division, that is to say, they were formed under conditions less active than those of pneumatolysis. Although the general form and structure of the lodes and ore bodies are similar to those of pneumatolytic origin, they differ in the respect that the lodes do not necessarily occur close to the igneous masses giving rise to them nor do they generally contain the characteristic minerals or altered country rock types of such deposits.

Not only have they been formed at a distance from the deep-seated igneous rocks, but frequently appear to have been derived from solutions emanated from them at a consider-

able period after their intrusion; or, in the more recent ore deposits, comparatively near the surface in association with the volcanic or hypabyssal rock types, such as andesitic volcanic breccias, quartz porphyries, etc.

Under the circumstances the only way in which to classify the veins is to group them according to the dominant metalliferous minerals they contain and to sub-divide these groups according to their dominant veinstones respectively.

By far the majority of the ores are sulphides, of which those of copper, zinc, and lead, and the pyritic deposits are the commonest, and occur either individually or as mixed types. Among the rarer ores included in the group are those of bismuth, antimony, arsenic, etc., which may occur as separate forms but are more commonly found with other ores as abnormal developments of ordinary lodes.

Pyritic or other sulphidic ores containing gold and silver in such quantity as to be the most profitable constituents of the lodes are known as gold or silver lodes respectively although the actual percentage of these metals present in the ore is very small.

Of the veinstones which give to the ores their more special characters the most important are quartz, chalcedony, jasper, etc., calcite, dolomite (occasionally ankerite), chalybite, barytes, fluorspar, and iron pyrites. It is therefore customary to use such terms as pyritic-, or siliceous-gold or copper ores, barytic-lead veins, argentiferous-lead-zinc-calcite veins, etc. Tellurium enters largely into the composition of one type of gold ores as in Cripple Creek, Colorado, where the well-known gold-telluride ores are associated with andesitic rocks of late Tertiary age.

To the oxidic class of ores, also belonging to the hydatogenetic group, belong carbonate and oxide of iron and manganese and hydrosilicate-nickel ores.

Deposits of *metasomatic* origin are referred to again in the following pages, but in their connection with lodes may be referred to here. They occur as replacements of the country rock near lodes. The most important of these are the irregular replacements of limestone by hæmatite and chalybite, galena, zincblende and cinnabar, but some come under the heading of lodes and others of impregnations according to the importance of the part played by metasomasis. In these cases the limestone in the vicinity of fissures or joints is replaced

particle by particle by the ores, so that the building up of the deposit is accompanied by the breakdown or corrosion of the country rock due to its interaction with the solutions which brought the ores. In a broad sense metasomasis is characteristic in more or less degree of most lodes, but it is only in the few instances named that it is the main factor in the ore deposition.

The walls of tin-lodes in granite are always altered by metasomasis, by which the felspar is replaced by tinstone, mica, topaz, and other minerals.

Massive deposits Derived by Differentiation or Segregation of Igneous Rocks.—Some ore deposits have been formed as products of consolidation directly from igneous rocks. In some cases the metalliferous minerals are important constituents of the rock itself, so that the whole igneous mass forms an ore deposit. More commonly there is a concentration of the ores at the outside of the mass, due to differentiation or segregation when cooling. In particular should be mentioned magnetite and titaniferous iron ores with sulphidic minerals such as pyrites, pyrrhotite, etc., and, in certain rocks, chromite.

The occurrence of native iron in inclusions of anorthite rock in diabase-porphyry in Greenland is of interest.

In New Zealand serpentines and olivine-bearing rocks, the nickel-iron mineral awaruite, chromite and chrome iron ores with the rock called dunite (olivine and chromite) occur, while similar ores with platinum occur in the Urals.

The most important segregation ores are those of magnetite and titaniferous iron ore, which in the Urals, Sweden, Finland, and the Adirondacks occur as differentiation products of basic igneous rocks such as gabbro or of orthoclase porphyry, in which the ore is found in small crystals and grains, in streaks or *schlieren*, constituting 20 per cent. of the rock but varying up to 65 per cent.

The sulphidic ores are also largely represented in this group of ore deposits and consist of copper and nickel sulphides.

In Norway the gabbro and norite intrusions are characterised by segregations of pyrrhotite with nickel and cobalt, iron and copper pyrites and titaniferous iron ore. These ores occur as masses situated at the edge of the gabbro between it and the surrounding schists. The famous nickel deposits

of Sudbury and arsenides of nickel in Spain are further examples.

At Monte Catini, in Tuscany, copper pyrites occurs irregularly distributed in a serpentenized olivine gabbro, evidently concentrated during serpentenization of the rock. The occurrence of copper pyrites in this way is rare, and is seldom of much value.

Some pegmatites contain rare minerals such as thorianite and monazite. In Malay decomposed pegmatite veins contain tin stone which is obtained by washing with water in the same way that detrital tin-ore is obtained from alluvia.

Stratified and Interbedded Deposits.—Some metalliferous deposits occur as beds in stratified rocks, having, like coal seams, been formed contemporaneously with the series of sedimentary rocks in which they occur. They may have wide, lateral extension as in some oolitic iron ores, or as in coal seams and salt and gypsum beds, or they may occur as lenticular deposits of limited area, though possibly of considerable thickness. Such deposits are frequently much disturbed, faulted or folded, particularly in the older rocks, and have been subjected to all the modifying influences which may have affected the stratified rocks of the region in which they occur. They are, however, of all ages, being contemporaneous with rocks varying in age from the pre-Cambrian to the superficial swamp and lake deposits of to-day. Such deposits should not be confused with what are known as bedded veins, which are merely true lodes formed in bedding planes of sedimentary rocks.

In the ancient schists and gneisses ore-beds of iron occur as metamorphic deposits in the form of specular hæmatite in Brazil, Norway, and other places. Reconstructed ores of carbonate of iron are found in metamorphosed Mesozoic limestones in Carinthia, where in places the ores have been altered by weathering actions and the limestone shows replacement by ankerite. Bedded deposits of hæmatite and magnetite as well as manganese ores occur in quantity in the crumpled, folded, metamorphic limestones and dolomite of the Archæan schists and gneisses of Scandinavia, and are of great commercial importance.

The hæmatite ores are connected mainly with gneisses, while magnetite is found in the limestones.

The iron ore deposits of North America (Michigan, Wisconsin, and Minnesota) are the largest in the world, and occur in folded pre-Cambrian rocks in schists, dolomites and quartzites and ferriferous rocks. The ores are mainly hæmatite and limonite, but in depth the ore is siderite, or spathic iron ore, the origin and structures of the deposits being complex.

Ores of iron and of manganese occur as bedded deposits in rocks of from Ordovician to quite recent age.

Oolitic hæmatite ore and spathic iron ore occur in Silurian greywackes and slates in Saxony and Bohemia. In the United States (New York State) oolitic hæmatite and other iron ores occur in beds many feet in thickness in Silurian rocks.

In the Jurassic (Dogger) of the Continent the famous oolitic ores or "minettes" of Lorraine are worked. In Eocene and recent formations ferruginous sandstones and oolites and bog iron ores occur respectively.

In the Carboniferous rocks of Great Britain the carbonaceous black band and clay ironstone ores are common in Wales and Scotland. Pockets of manganese ore occur in the lower culm in Austria, Cornwall, and in Spain. The Permian and Trias of the Continent (Tyrol) contain beds of hæmatite in slates and limestones.

In the Lias of England the famous Cleveland iron ores occur.

Impregnations and Replacements in Stratified Rocks.—Metalliferous solutions are able to penetrate sandstones and other porous granular rocks and to be deposited in them, forming ore-deposits of tabular form. Limestones are readily replaced by some solutions which act upon the limestone, removing it molecule by molecule, putting in its place galena, zinc or iron ore, etc.

Since impregnation many of the deposits have been metamorphosed, and so occur as metamorphic types in schists and quartzites.

Ores of pyritic zinc-lead with accessorv ores occur in the Western Erzgebirge in connection with pyroxene-hornblende rock much altered to jasper, epidote and chlorite.

Similar impregnations and lenticular bodies are found in Pitkäranta (Finland), where sheared hornblende pyroxene-garnet gneiss is impregnated by the same ores with occa-

sionally molybdenite, scheelite, cassiterite, bismuth, and native copper, copper pyrites, and pyrrhotite.

In Scandinavia and in Tennessee certain bands of the crystalline schists and gneisses are impregnated with copper and iron pyrites and a little zincblende, and these ores appear to have been introduced before metamorphism of the rocks. The ore bodies, however, are traversed by secondary veins. Cobalt and pyritic ore occur in crystalline schists of Skuterud in Norway and in the Caucasus, while gold in quartz lenticles and in association with pyritic ores are found in Dakota and in the Appalachians, and in Brazil, Africa, and other places.

In the non-metamorphic rocks similar deposits are met with and present many features in common with the dynamically or contact-altered deposits, impregnations of copper and iron pyrites, galena, zincblende, and barytes being found in Palæozoic and newer rocks.

The Huelva deposits in Spain containing iron pyrites and copper pyrites, and the Mount Lyell (Tasmania) impregnations containing silver, gold, and copper ores are further examples.

The Mansfeld copper-bearing bituminous calcareous shales, at the base of the Bunter, are well known, and similar occurrences are found in other regions in beds of varying ages.

The galena of Mechernich (in the Rhineland) occurs as impregnations in the form of granules and small cementing lumps throughout certain calcareous, argillaceous sandstones of the Bunter.

The gold of the West African and Witwatersrand bankets is supposed to have been deposited from auriferous solution subsequent to the formation of the conglomerates, but the origin is not known with certainty.

Among rarer deposits of the type formed by impregnation of beds may be mentioned some ores of antimony. In Prussia, for example, stibnite and antimony ochre occur in the Upper Culm beds in fissures and as impregnations in shales and sandstones.

Replacements.—Of the more massive forms of bedded deposits may be mentioned the true replacement of limestone beds by iron and manganese ores, copper, lead, and zinc, and even of silver, gold, and antimony. These deposits are truly metasomatic.

The hæmatite ores of the Forest of Dean and in Cumberland are replacement deposits in Carboniferous limestones, while the replacement deposits of Cretaceous limestones by spathic iron ores in Bilbao are important examples of metasomasis.

Manganese carbonate and oxide replaces limestones of Upper Devonian age in the Pyrenees.

Carbonates and oxides of copper, and native copper with a little sulphide, occur with manganese and iron ores in Carboniferous limestones and Arizona; but the best examples of metasomatic replacement of limestone beds are those of lead and zinc. These deposits are numerous and of all ages, and occur, wherever lead or zinc is found with limestones, in England, the United States, Mexico, Austria, Germany, Spain, Greece, Italy, and Tunis. The deposits are extremely irregular, and replacement appears to have commenced from joints and bedding planes with formation and gash veins, and by degrees gradual replacement of the whole rock. The deposits in the limestones of the Mississippi valley are examples of these, and here the ores are associated with the usual fluorspar and barytes. The Carboniferous limestones of Derbyshire contain replacement deposits of galena, accompanied by other minerals such as fluorspar, zinc ore, quartz, pyrites, and barytes.

The replacement of dolomite by siliceous gold ore is exemplified in the Cambrian series in South Dakota, while similar modifications are known from the Transvaal.

True metasomatic replacements of limestone by antimony ores are known in the United States, Italy, and Servia.

Contact-altered Bedded Ores.—Some original bedded ore deposits formed by impregnation or metasomatic replacement have been altered or modified since their formation by the effect of contact with later intrusions of igneous rocks. The result is that the deposits are generally disturbed and characterised by the presence of minerals of contact origin and evidently derived from the previous minerals of the deposit. Metamorphic minerals derived from lime-bearing shales or limestones are garnet, epidote, wollastonite, pyroxenes, and other minerals. The ores coming into this group include magnetite and specular iron ore, ores of copper and other sulphides, galena and even gold, and in all cases the deposits have been reconstructed.

Magnetite occurs in shales and limestones near the metamorphic zone round granite in Saxony and Bohemia. In the Isle of Elba specular hæmatite replacing Liassic limestones overlying Permian dolomites and quartzites is formed by contact with plutonic intrusions. Another example is the contact deposits of Banat in Hungary, where magnetite is found at the contact of dacite intrusions and Tertiary limestones; and in Archæan schists. The magnetite and hæmatite in Archæan rocks near granite in the Christiania basin has long been known.

Sulphidic ores of copper with zincblende, galena, mispickel, sulphide of iron, and rarer ores occur in association with garnet, epidote, and pyroxene in dolomitic limestone bands in mica-schists near their contact with dioritic intrusions in Piedmont.

In Tuscany sulphides of copper, iron, galena, and zinc occur in marmorised, altered Liassic limestone in the vicinity of complex dykes.

NON-METALLIFEROUS DEPOSITS.

The non-metalliferous deposits can be more or less classified in the same way as the ores, but owing to the nature of many of the minerals varying widely from those described in the last section, the grouping is more or less arbitrary, and largely one of convenience. Many rocks, both sedimentary and igneous, are of economic value as building or ornamental stones. Such rocks as marble and other limestones, freestone, granite, diorite, serpentine, etc., are too well known to need a reference to their uses.

Vein Deposits.—The non-metalliferous minerals occurring as veins traversing other rocks, include such substances as ozokerite and other bituminous solids, barytes, fluorspar, cryolite, asbestos, magnesite and apatite.

Ozokerite occurs in veins and brecciated masses in Miocene sandstones and shales in Galicia. Barytes and fluorspar are met with alone or in association with lead or other lodes. In Shropshire barytes is worked in lodes containing scarcely any other mineral. Barytes and witherite are also found in Spain and New South Wales. Strontianite occurs as an associate of barytes. Cryolite is found in Greenland with

siderite, wolfram, galena, copper and iron pyrites, fluorspar and quartz, in the form of veins and masses in granite and gneiss. Magnesite occurs in veins in serpentine in California, Styria, and other places. Apatite is found in association with pyroxenite in the Laurentian rocks of Canada. It occurs in large lodes in Spain. Asphalt is found in brecciated veins in Chieti (Italy) and other bituminous localities.

Chrysotile or Canadian asbestos is found in veins in serpentine, the principal localities being Thetford and Coleraine (Quebec). The true asbestos is a fibrous variety of hornblende, and is found in veins in many metamorphic regions. For veins of sulphur *see* "Impregnations (p. 55)."

Bedded Deposits.—The bedded deposits of non-metalliferous minerals are of various origins, but all are either accumulated, fragmentary, or granular materials, or are precipitations from solutions. Some of the minerals show concretionary structures, while others, as in the case of coal, have been extensively modified since the bed was laid down and covered up, and might, as in the case of some anthracite deposits, be referred to as metamorphic types. Coal occurs in beds of large extent and varying thickness in the Carboniferous formations of many countries, having been formed by accumulations of plant remains in swamps, deltas, lagoons, or enclosed seas. Lignite or brown coal is less altered and is generally representative of coal, and is of importance on the Continent, particularly in Germany. Peat is the recent superficial decayed or decaying vegetable accumulations commonly found in bogs and occasionally on hill slopes. In valleys it is often covered by ordinary river detritus. Bauxite, which is the principal source of aluminium, occurs either in the form of oolitic beds in association with limestone, as at Beaux, or as lake deposits supposed to be in some way connected with solfataric action.

Alum is found in the British Islands in clays and shales. Gypsum occurs as nodules and layers in marls and shales of early Tertiary and Mesozoic rocks. In Paris it occurs in the Eocene in lenticular beds 50 feet thick, and in Nottinghamshire in lenticular masses and veins in Keuper Marl. Native sulphur is found in Sicily in Miocene marls and white lime-

stones, and occurs as globules or crystals with calcite, gypsum and bitumen, the adjacent beds being radiolarian and tufaceous rocks. The sulphur is supposed to have been a chemical precipitate deposited in a lake contemporaneous with limestone, and not to be an impregnation.

The oil shales of Scotland contain a little bitumen, from which oil, paraffin, and ammonium sulphate can be distilled.

Phosphates, so extensively used as fertilizers, are principally derived from pockets in Eocene and Miocene limestone in New Zealand and in Florida. Their origin may be partly metasomatic. Apatite and secondary concretionary phosphates have been worked in rocks of all ages, but the principal deposits occur in Tertiary formations.

In Tunis and Algiers calcium phosphate occurs as phosphatic limestone, or as nodules in Eocene marls. In the Chalk of England (Bedford, Cambridge, etc.), France and Belgium, phosphatic nodules occur, while in Tennessee the mineral occurs in Ordovician limestone.

Amber is a fossil resin occurring in blue Tertiary clays along the south coast of the Baltic.

Of the bedded earthy minerals of use may be mentioned Tripoli (diatomaceous rocks); fire-clay, which is often associated with coal seams, being found under them; and natural cement, as that of the argillaceous limestone of Grenoble (France).

Fuller's earth is a brownish green soapy mineral, consisting of hydrous silicate of alumina. It is found in Surrey and Bedfordshire.

Common roofing slate is a hard, well cleaved, dynamically metamorphosed argillaceous rock, with a clear ringing sound when struck, and with no very pronounced earthy odour when breathed upon.

Many compounds of the alkalis and other salts are the result of the evaporation of saline solutions such as sea-water, and are not ordinary sedimentary but precipitated deposits. The conditions under which the "caliche" (nitrate of soda) of the arid deserts of Chili occurs are of interest. The nitrate of soda is found in beds varying from a few inches up to 12 feet in thickness, overlain by conglomerate of from one to 10 feet. Associated with the caliche are gypsum, sulphate of soda, and common salt. There are several theories accounting for the origin of the salt, but the most likely

one appears to be that the salt was originally deposited from sea-water or a salt lake as common salt, but that under the desert conditions by the action of decaying animal and vegetable matter the salt was converted to nitrate.

The potassium salts (carnallite, etc.), of the Bunter in Stassfurt are due to drying up of an old sea. Similar salts occur in Persia in association with common salt. Common salt is often obtained by pumping the water from wells sunk through saliferous marls and salt beds. In Cheshire there are two beds of salt in the Keuper, and in Durham the salt beds are probably Permian in age.

Borate of lime occurs interbedded with shales in California.

Impregnations.—Asphalt occurs as impregnations in sandstones and limestones and as superficial deposits in lakes.

In Italy (Chieti), Switzerland, France, Germany, Trinidad, and the United States, asphalt and other bitumens are worked. As impregnations in Mesozoic sandstones it is found in California; as brecciated veins and impregnations in Eocene (nummulitic) limestones on the Continent and in Texas and Utah. The material used for the roads is a limestone containing no argillaceous material but about 13 per cent. of bitumen. In the preparation of mastic for paths the solid bitumen is obtained from porous limestones by heat.

Petroleum and its gas occurs in porous rocks of all ages, but is particularly abundant in late Carboniferous and early Tertiary rocks, being found in domes or anticlines in porous rocks with an impervious cover. It is supposed to have originated from the change of organic matter previously existing in the rocks, and in this sense should be grouped with the bedded deposits. It is notably abundant in Baku, Galicia, Pennsylvania, Ohio, Texas, California and Burmah.

Barytes sometimes occurs as an impregnation in schists.

Native sulphur occurs both as veins and as impregnations in porous rocks. In Iceland and near Naples it is obtained from solfataras near volcanoes. The native sulphur is produced by mutual decomposition of sulphuretted hydrogen and sulphur dioxide. In Utah the sulphur occurs in veins and impregnations in rhyolitic tuff, and appears to be connected with volcanic emanations of sulphuretted hydrogen which become oxidized by air with precipitation of native sulphur.

Deposits in Lake Basins, etc.—These differ from the bedded deposits or impregnations referred to in their being recent superficial accumulations in lakes.

Borax or "tincal" occurs with clay in tropical countries under desert conditions, where rapid evaporation takes place and the rains are periodic or absent. The decomposition of felspars in lavas results in the liberation of carbonates of soda, which are washed into the lake and dried, and are collected as efflorescence. The borax is probably formed by fumarole action and dissolved in the same way. Such lakes occur in California, and Nevada, South America, Italy, and Thibet.

Boric acid is obtained from fumaroles or steam puffs or blowers in Italy, near Pisa, where the method of obtaining the acid is to dig a small pit round the fumarole and fill it with water, which is allowed to become saturated with the salt and finally evaporated.

The famous pitch lake of Trinidad is an accumulation of bituminous material derived from some subterranean source.

The "caliche" or Chili saltpetre is described under "Bedded Deposits (p. 54)."

The hydrous carbonates of soda—natron and trona—occur as superficial deposits in some parts of the world. As an efflorescence they are found in Egypt in lakes; also in Hungary and Mexico. Trona occurs in the Gulf of California as a solid layer from one to two feet thick over a small lake consisting of saturated solution of carbonate of soda.

Peat, which is already referred to under "Bedded Deposits" (p. 53), may also be included in this group. It is essentially a recent formation.

Metasomasis.—Alunite, from which alum is obtained, occurs in veins and in masses in Tertiary trachytes, and acid lavas, from which it was derived from the felspars by re-action of solfataric solutions on them. The principal occurrence of this material is at Civita Vecchia, near Rome, but it is also found in felsitic dykes in New South Wales. The deposits might be classed with the veins. Deposits of metasomatic origin are those of China clay resulting from the alteration of felspars, and of barytes in limestone.

In the East and West Indies the phosphate of lime occurs as a replacement of coral reefs by the action of phosphoric

acid derived from the guano of birds, the action being a metasomatic one (*e.g.*, Christmas Island, East Indies).

Meerschaum is a silicate of magnesia occurring in serpentine and as irregular deposits in limestone; it is found in Asia Minor, Greece, Morocco and Spain.

Volcanic Breccias.—The diamond occurs with garnet, magnetite, olivine, and other igneous and metamorphic minerals in breccia of volcanic pipes in Kimberley (South Africa).

The breccia consists of serpentinized peridotite with black shale, diorite, and granite. The original source of the diamond is supposed to be eclogite.

Segregation.—Mica is derived exclusively from pegmatites, the principal localities being India, Canada, and North Carolina.

Metamorphic.—Many precious stones are derived from mica schists, gneisses, and metamorphic rocks. Graphite is also found in crystalline schists and gneisses in Ceylon and Austria.

Steatite or talc (soapstone) occurs in lenticles in schistose magnesian rocks, derived from serpentine and metamorphosed magnesian limestone. Jade is found in metamorphic rocks.

Some of the minerals mentioned above might be included in this group as they have undergone various kinds of chemical change since first formed, but as practically all minerals are liable to change of some kind, the metamorphic group is confined to the few instances mentioned.

GLOSSARY OF TERMS USED IN GEOLOGICAL SECTION.

ACID.—In connection with igneous rocks implies a high percentage of silica, either free or combined.

ALLUVIUM.—The muds and sands deposited by rivers when they overflow their banks. Easily recognised by the flatness of the ground between the river bank and the side of the valley.

ALTERATION.—This is the change effected in minerals or rocks by heat through contact with intrusive rocks; by pressure, or by the action of solutions or thermal water.

BASIC.—In connection with igneous rocks implies a low percentage of silica and a high percentage of such bases as lime, magnesia, soda, potash, iron, etc.

Batholith.—A large intrusive mass, generally plutonic in character.

Breccia.—Crushed rock of any kind cemented by some mineral such as quartz, calcite, oxide of iron, etc.

Cleavage.—Of two kinds. In minerals it means the tendency to split in definite directions. There may be one, two, or three planes of cleavage, and some easier than others. In rocks, a cleavage is often found in those which have been subjected to pressure, as in slates, so that the rock has a tendency to split more easily in one direction than any other. Massive rocks, such as granite, have a tendency to break more readily in some directions than others.

Concretionary.—Refers to the formation of a mass or nodule round some point in the rock. Concretionary structures are very varied and the chemical actions producing them are complex and not thoroughly understood. Principally in limestones.

Contemporaneous.—In geology refers to age of rocks. A limestone in one part of the world may be contemporaneous with a sandstone formed at the same time in another part. Coal seams are often said to be contemporaneous with the beds above and below, but this is not strictly true, and is often entirely false; ore veins and intrusive rocks, by their nature, cannot be contemporaneous.

Crypto-crystalline.—Refers to the texture of igneous rocks. Where the groundmass is not glassy but so finely crystalline that the individual crystals cannot be made out by the microscope.

Current-bedding.—Sands deposited under running water often show an oblique bedding which runs across the plane of deposition as a whole.

Denudation.—Disintegration and removal of land by atmospheric agencies.

Devitrification.—An igneous rock which was originally glassy and has through time developed a microscopic crystalline structure is said to be devitrified.

Differentiation.—Applied to igneous rocks implies the separation of a molten igneous magma into two or more magmas of different composition.

Dip.—(Compare Underlie.)—The dip of rocks is the angle which the planes of bedding or cleavage make with the horizontal.

Epigenetic.—Used in connection with mineral deposits means those formed subsequent to the rocks in which they are found, *e.g.*, lodes.

False Bedding. *See* Current-bedding.

Fissility.—The tendency of a rock to split into thin flakes.

Formation.—Is an indefinite term used to indicate a geological unit, irrespective of its actual structure. The "granite" formation, the "dyke" formation, the "clay slate" formation. It often has reference to age, as, "The Silurian formation."

Fossils.—The harder parts of animal or plant remains which have been preserved in rocks from the time they were covered over during the building up of the rock. As they are truly contemporaneous they are useful guides to the ages of the rocks.

Granophyric.—Refers to the microscopic structure of the ground mass of certain rocks. The granophyric structure is a microscopic intergrowth of the felspar and quartz of the ground-mass.

Ground-Mass.—Used in connection with igneous rocks. In rocks which are not porphyritic the whole rock is the ground-mass. In porphyritic rocks all the rock except the isolated minerals, *e.g.*, the porphyritic felspars, is "ground-mass" whether crystalline or glassy.

Hydatogenesis.—*See* definition given under heading "Origin and Nature of Lodes" (p. 44).

Hypabyssal.—In connection with igneous rocks implies those intermediate between plutonic and volcanic rocks. Hence it refers to texture as well as situation. The typical hypabyssal rocks are ordinary dykes.

Impregnation.—The deposition of minerals in porous or granular rocks through the percolation of mineral bearing solutions; generally in rocks near a lode. The action is often accompanied by a complete change in the character of rock due to other reactions.

Individualization.—Used in expressing the free growth of minerals in a consolidating igneous material.

Laccolite.—An intrusive igneous mass of moderate dimensions. Owing to its viscosity or to the structures of the rocks among which it was intruded it did not assume the ordinary common dyke form.

Magma.—The molten silicate solutions which on consolidation give rise to the igneous rocks. There are "basic" and "acid" magmas.

Metamorphism.—The change in the character (mineral composition or structure), of a rock as effected either by heat, or in changes brought about through contact with intrusive rocks, or by pressure. Strictly it is applied to alterations effected without the removal of any of its minerals or the addition of fresh substances.

Metasomasis.—*See* definition given in section entitled "Origin and Nature of Lodes" (p. 44).

Oolitic.—Refers to a granular rock—generally limestone—in which the grains are spheroidal or egg-shaped. The grains have been formed, in the case of limestones, in clear but moving water so that small grains have been built up into larger by addition of lime.

Pisolitic.—Similar to oolitic structure but the grains are much larger.

Plutonic.—Deep-seated. Used in connection with igneous intrusives, it means that the rock consolidated at a great depth and is consequently coarsely crystalline.

Phenocryst.—A porphyritic crystal is a phenocryst. The more or less complete crystals of felspar, quartz, mica, etc., which occur here and there through the ground-mass.

Pneumatolysis.—*See* definition given in section entitled "Origin and Nature of Lodes" (p. 44).

Porphyritic.—A rock which is porphyritic consists of a ground-mass, either glassy or completely crystalline, in which are set more or less perfectly formed individual crystals, *e.g.*, granite containing porphyritic crystals of felspar.

Reconstruction.—The change effected in minerals or rocks through thermal or dynamic Metamorphism.

Regional.—A term used in reference to changes in character of rocks over large areas. The rocks may have been altered at depths by terrestrial heat and crustal pressure.

Replacement.—When one mineral is decomposed and replaced by another, *e.g.*, felspar replaced by china clay. Sometimes the entire mineral has been removed and another has taken its place as in felspar replaced by "pseudomorphs" of tin ore.

Segregation.—Applied to ores derived from igneous rocks implies the localisation or concentration of certain minerals which separated out from the molten igneous magma. Concretions are another type of segregation.

Stratigraphical.—Refers to the relative positions and consequently the ages of the different members of a series of stratified rocks.

Strike.—In tilted stratified rocks, or in dykes, faults and lodes it indicates the horizontal direction of the planes of bedding or of the walls respectively. A bed dipping north or south "strikes" east and west.

Syngenetic.—In connection with mineral deposits means those formed contemporaneously with the rocks in which they are found, *e.g.*, alluvial deposits, bedded iron ores, pegmatites, &c.

Twinning.—Two crystals of the same mineral united together in a symmetrical manner by similar crystal faces.

Unconformity.—A stratigraphical break, where the process of sedimentation has been suspended for a considerable period, as where the sea floor is raised for a time above sea level; the sediments which are laid down subsequently are said to rest uncomformably on the other rocks. The break is often indicated by a conglomerate and it is often noticed that the newer rocks extend across the denuded edges of the older beds.

Underlie.—(Compare Dip).—The angle which the plane of a lode, dyke or fault makes with the vertical.

Vitrophyric.—Used in describing volcanic rocks where the ground-mass is glassy.

Volcanic.—In reference to rocks means the material blown out as dust and fragments, or poured out as lava from a volcano. As a rule the lavas are glassy rocks, although the others may be devitrified.

PANNING.

This process depends on the manipulation of earth, sand, or powdered ore in a "pan" with water, the object being to separate, with the aid of water, the lighter (usually the worthless portions) from the heavier mineral. Two kinds of pan are in general use. The prospector is generally accustomed to handle the ordinary "gold-pan" which is useful for panning gold and cassiterite from alluvial. For the panning of ores in powder, for example, powdered tin-stone, it is best to use either a light iron dish or batea, made in the shape of a sand-bath, 12 inches across and "dished" 2 inches in the middle. A convenient quantity of material is placed in the pan and clean water is added, and after thoroughly wetting the ore by rubbing it in the water with the fingers, the mixture of ore and water is shaken so as to cause the heavier portion (containing the mineral) to fall to and remain at the bottom of the pan, while the water containing the earthy matter can be caused to flow over the edge. This is repeated till the supernatant water is clear, and then most of the water is poured off, and a rotary motion is given to the pan so as to cause the various constituents of the mineral under examination to spread out, the portions of highest specific gravity separating themselves from those that are lighter.

The mode of operating the pan cannot be learnt from a written description, but is easily seen in practice. While it requires considerable experience to separate minerals without loss in this way, a sufficient degree of dexterity to separate them well enough for subsequent examination is soon acquired.

In many cases, as, for example, with free-milling gold (*i.e.*, gold present in the free state, not enclosed in pyrites, etc.), pannings are almost as useful as assays would be, and have the advantage that many pannings can be made in the time required for a single fire-assay.

In testing lode-stuff or alluvial for gold, the small quantities of gold should be washed out into a dish after each panning, and the total quantity dried and wrapped in a little piece of lead foil and cupelled, when a bead will probably be obtained of sufficient size to admit of accurate weighing, whereas the bead from *one* panning (except in the case of an exceptionally rich ore) would be too small to weigh accurately except on a very delicate balance. This bead should be kept to be "parted," that is, to determine how much silver is present with the gold, as native gold almost always contains some silver, usually from 2 or 3 up to 10 per cent.

The dirt is added a part at a time if there is too much to go on the pan conveniently at one time. The ordinary pan will hold when full about 18 lbs. of average earth, and about 120 to 125 pans are equal to one ton.

If a quarter of an ounce of a mineral, cassiterite, for example, is obtained on panning one dish of dirt, the yield per ton will be about 2 lbs.

A small pair of weighing scales with gram or grain weights can usually be obtained from any chemist's shop, and as they occupy a very small space (about 8″ × 4″ × 1½″), they will be found very convenient for weighing the results of pannings. For weighing large quantities, from 1 lb. to 25 lbs., an ordinary spring balance such as is used by fishermen is very convenient.

A "panning assay" may be made in the case of many ores, such as those of lead, tin, etc., that is to say, by taking a weighed quantity of the ground ore passed through a 30-mesh sieve, by careful panning the earth and gangue may be washed away till the ore is obtained clean. This, of course, depends on whether the mineral and the gangue are sufficiently different in their specific gravities to enable a complete separation to be effected by water.

Thus a tin ore can generally be panned free from the gangue accompanying it, because the cassiterite has a specific gravity of about 7, and the specific gravity of the gangue will be about 2 to 3; but if the ore contained micaceous iron or wolfram

(both of which have a gravity nearly the same as cassiterite), a clean separation in the pan is either very difficult or impossible. A separation can, however, be effected by the aid of a powerful electro-magnet or by chemical means, but not by a hand-magnet.

The behaviour of ores in the pan is of high practical importance, because most ores have to be dressed by the aid of water, and the ease or difficulty experienced in panning will indicate to a large extent the ease or difficulty to be expected in dressing on a working scale.

The pan is used in the laboratory not only to ascertain the presence of certain minerals which cannot always be seen when distributed in rock, but to make rough estimations.

In the field, operating on larger quantities, it is used not merely as a means of testing deposits, but also as an appliance for saving gold, etc. It is, of course, obvious that, with an instrument of this sort, only a very small quantity of material can be dealt with daily, say about half a ton of earth, sand, or gravel. Where appliances capable of dealing with larger quantities can be employed, the "cradle," the "tom," and the various forms of "sluice-boxes" would naturally be used on account of their capacity for dealing with much larger quantities of material.

VANNING.

In Cornwall the vanning shovel is used for determining the percentage of tin-oxide in tin-stone, also in some cases the percentage of wolfram and mispickel in their respective ores. With care and practice fairly accurate concentrations may be obtained.

The vanning shovel is manufactured locally, and consists of a thin sheet-iron plate, weighing between 2 and 3 lbs., it is 14 to 15 inches long by 13 inches wide, and dished nearly 1 inch in the centre and has a socket or "eye" to receive the handle; the back part of the shovel on either side of the eye is slightly turned up; the handle, which is short proportionately to other shovel handles, is usually of ash or hickory, and has a bend or turn up a little way from the socket and is about 3 ft. long; the face of the shovel should be smooth and kept bright. In the hands of a skilled vanner the extraction of mineral from its gangue is an easy process. The sample to be vanned is usually crushed to a 30 mesh powder before being vanned. If the mineral is *finely* disseminated throughout the rock, it may be necessary to recrush the tailings to a 60 mesh powder.

The vanner stands before a tub of clear water holding the shovel level and places the ore to be vanned in the centre of the blade, he then lowers it and takes up a quantity of water over the edge of the shovel and washes the ore round and round until all earthy matter and slime are got rid of, using fresh quantities of water as required and discharging the slimy water over the side. The ore now rests in the middle of the shovel and should be washed with a small quantity of clear water by circular motion a little way towards the point of the shovel, and the heavier portions thrown up by a series of "cants" or jerks further towards the point, the circular washing being kept up at intervals between the "cants," bringing back the lighter portions or gangue. In case the lighter parts which have been washed back are not sufficiently fine, they should be bruised or pulverised by rubbing with a hammer on the back part or "heel" of the shovel and again brought to the centre and thrown up as before, care being taken not to interfere with the "edge" of mineral first thrown up; the gangue or waste is washed at intervals over the side of the shovel at the discretion of the vanner.

When tin-stone is being vanned it is usual to roast or "calcine" the sample in a crucible on a slowish fire, after being weighed and before being treated on the shovel to remove sulphur, arsenic, etc., which may be present; a common practice is to remove iron by means of a strong magnet. If this is not done the "edge" or "head" of mineral which has been thrown up must be roasted in a crucible, and the iron removed by magnet, or, better still, boiled in a porcelain dish with hydrochloric acid for a short time, and again boiled with the addition of nitric acid about half the bulk of hydrochloric present, again brought on to the shovel and vanned, and after being dried by holding the shovel over a fire or furnace is carefully brushed off and weighed.

The quantity usually taken is 1 oz. troy, but in cases of fairly rich ore ½ oz. or even ¼ oz. is quite sufficient to make an assay.

If 1 oz. is taken and the amount of mineral vanned out or separated equals 1 grain, 1 grain equals 4·66 lbs. mineral to the ton of ore, one grain being the 480th part of 1 ounce and 2 grains equal 9·32 lbs. mineral to the ton of ore, and so on proportionately.

The vanning shovel may well be used for obtaining an idea of the quantities of many minerals in a ton of ore, and, as before stated, with some minerals fairly accurate results can be obtained with care and practice, *but it must not be assumed that the concentrate so obtained consists entirely or even chiefly of the mineral which is intended to be separated.* This

is specially of importance in tin ores, where oxide or carbonate of iron, or sulphides of iron, arsenic or zinc, are often present. The concentrate should therefore *always* be cleaned by an acid treatment as above described. Where wolfram may be present in addition, a fine grinding followed by prolonged boiling for several hours in aqua-regia is required. The tungstic acid must be removed by digesting the concentrate (previously washed free from acid) in ammonia.

Alluvial Deposits.—When minerals insoluble in water have been set free from the rock in which they originally occurred owing to the weathering action of air and water, and have been washed down on to lower ground and deposited there, the deposits are termed "alluvial." If these deposits are recent they often contain various minerals, usually the oxides of the heavy metals, or in the case of Gold and Platinum, the metals themselves. They are then described as "Native." Minerals that can be decomposed by weathering will be altered, and by forming soluble compounds may be entirely removed.

Thus compounds of copper, lead, zinc, antimony, bismuth, etc., are not likely to be found in old alluvial deposits. On the other hand, those minerals that are quite insoluble in water and are unaltered by weathering will remain unaffected.

Among such minerals that are likely to be found thus are the gem-stones, gold, platinum, cassiterite, magnetite, titaniferous iron ore, monazite sand, zircons, precious stones, osmiridium, cinnabar, etc.

If the alluvial ground containing the minerals is soft and not cemented together with lime, iron-compounds, or clay, the separation of the mineral from the earth, sand, etc., can often be effected by simple washing. If the earth is cemented together or clayey it may require crushing or puddling. To separate minerals from earth or gangue of a lower specific gravity on a small scale the pan may be used. The use of the pan and of the vanning shovel has been already described.

The utmost quantity of earth that could be dealt with by one man with a pan in a day's work would be about 12 cubic feet or ½-ton, and this would only be possible if the material were soft and easy to pan.

With a cradle perhaps two or three times this quantity could be dealt with, and with a "long tom" or sluice-box operated by two men, several tons can be washed.

A "ground-sluice" is simply a ditch dug in the ground carrying water, and the material to be concentrated is thrown or washed into it, care being taken that no blocks occur owing to the accumulation of roots or stones.

The mixed mineral and gangue is shovelled or moved with a hoe towards the head of the sluice. At suitable intervals the sluice is cleaned up and the mineral removed.

If gold is the metal which is being sought for, amalgamated plates, strips of blanket, or carpet are used. If cassiterite is the mineral in question, stops, blocks, or riffles are inserted at suitable intervals.

The ground-sluice is employed in cases where it would not pay to construct wooden sluice-boxes. A properly made sluice-box requires far less water than a ground sluice. The amount of fall or slope given to sluice-boxes is usually about one inch in two feet, roughly 4 per cent., but the requisite fall is best determined by actual experiment.

Sluice-boxes are made of planks nailed or bolted together, the end of each length fitting into the next one, and in large scale operations they are often made some hundreds of feet in length. The bottom is protected from wear by either a layer of stones or by nailing down lengths of tram-rail.

A certain loss of mineral is sure to occur in sluicing, particularly if the mineral is fine, but sluicing has the advantage of simplicity, and enables very large amounts of low-grade material to be dealt with.

Where it is possible to bring on water at a pressure of 100 lbs. or more on to an alluvial formation, and to wash down faces of mineral-bearing earth or soft rock into a sluice, and the tailings can be dumped without having to elevate them, a very small percentage of mineral will yield a handsome profit.

When gold, cassiterite, etc., occur in soft ground where there is no head of water for sluicing, or no convenient fall for dumping the tailings, they are sometimes worked by dredging.* If the mineral-bearing sand is in a river the dredge is built on a barge and is moved along gradually as the sand is worked out. The dredge may be either a bucket dredge or may operate by suction. Arrangements are usually made whereby the tailings are stacked on the bank by a conveyer. Solid ground may be dredged, the dredge floating in a pond dug out for its reception. The tailings are stacked behind it, as it works its way along. This is, of course, only practicable where the level of the ground-water is suitable and where a sufficient amount of clean water can be brought in for washing the mineral-bearing dirt.

Soluble Minerals.—A list of the minerals, soluble in water,† that occur in nature will be found on a later page. The most

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* See "Hydraulic Mining" by Captain Longridge.

† Every mineral that is soluble in water is of commercial value, providing, of course, that it exists in workable quantity.

important of these are: common salt (sodium chloride), the nitrates of potassium and sodium, borax, certain potash salts, etc. Copper salts occur in solution in the water of certain mines, and are utilised in the preparation of "cement copper" (*see* under "Copper").

When crystals, or incrustations, or earthy deposits impregnated with a soluble salt are discovered, an average sample should be taken and a weighed quantity boiled with water, strained through a cloth, the earth being washed on the cloth two or three times with hot water and the solutions added together and boiled down. When evaporated to dryness the resulting residue should be weighed, and after the chief constituents have been identified, an average sample of the deposit should be sent away for a complete analysis.

THE RECOGNITION OF MINERALS.

GENERAL PROCEDURE.

In order to identify any mineral, or to ascertain whether any given stone contains a mineral of value, the following general procedure may be adopted:—

Powder a portion of the stone till it will all pass a 30-mesh sieve. Pan it, and note whether it appears to be all uniform, or whether it consists of two or more obviously different materials. [If different portions can be separated, treat them separately.]

Physical Tests.—Take a larger piece of the mineral and carefully examine it as to colour, presence or absence of "metallic lustre," and apparent specific gravity (by simply handling it). Also try the colour of the streak, note whether the specimen is notably crystalline or not, whether it possesses a good cleavage, and whether it is either hard or soft. The above physical characteristics will often be sufficient to place the specimen in one of the groups, and perhaps will show that it is probably one of two or three particular minerals.

Colour or Lustre.—As "colour"* is largely a matter of opinion, and colours are apt to vary, it is important to compare the descriptions given with actual specimens.

"Metallic lustre" is a valuable feature which distinguishes many metallic ores, particularly the sulphides of many metals. Those minerals possessing a metallic lustre have been divided into two groups. Firstly, those which possess a yellow metallic lustre, and, secondly, those whose lustre is metallic but without any yellow tinge. The latter class includes all those that are variously described as silver-white, tin-white, lead-grey, steel-grey and iron-black. It would serve no useful purpose to separate this group into classes, as the brightness or tint of the lustre varies with the exposure to the air and the consequent tarnishing.

In some minerals the metallic lustre is very bright, as in galena, while in others, such as wolfram or tantalite, it is variously described as "sub-metallic," "glimmering," or "quasi-metallic" lustre. Many minerals which have no metallic lustre possess a lustre which is capable of description; for example, atacamite has a vitreous or glassy lustre, and so has

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* A classification based on colour was suggested by Werner in 1774, and a good description of colours of minerals is contained in "An Introduction to the Study of Minerals," by L. Fletcher, M.A.

quartz; cassiterite and blende have frequently a resinous lustre, and some gem stones have an adamantine lustre. Substances having no lustre at all would be described as dull or earthy in appearance.

Specific Gravity.—The specific gravity of a substance is its weight, divided by the weight of an equal volume of water, at 60° Fahrenheit.

It is a simple matter to take the specific gravity of a solid mineral which is insoluble in water. The mineral is suspended to the pan of a balance by a hair or piece of thin thread and weighed.

It is then weighed submerged in water. The figure obtained by dividing the weight in air by the weight in air after subtracting the weight in water, is the specific gravity.

(In Air) Weight of specimen = 30·2200 grams.
(In Water) - - - = 21·6440 „
Loss of weight - = 8·5760 „
Sp. gravity . - = $\frac{30·2200}{8·5760}$ „ =3·52

In the case of a solid fragment the operation is performed quite simply, the only precaution necessary being to see that no bubbles of air adhere to the mineral when submerged.

If the material is a powder, its specific gravity can be taken by powdering it very fine and weighing it in a specific gravity bottle, whose weight and capacity when filled with water is accurately known.

Certain high-gravity solutions are employed in ascertaining the specific gravity of gem stones. For the composition of these and the method of their employment, the Author would refer the reader to "The Gem Cutter's Craft," by Leopold Claremont.

The specific gravity of most common rocks and stones varies from 2·0 to 3·0, that of most metallic ores is above 4·0, while many are from 6·0 to 8·0. A small amount of practice will enable one to tell by handling whether a stone is notably above 2·0 to 3·0, in which case it very probably contains some useful mineral.

Streak.—Sometimes the colour of the powder of a mineral is distinctive. Minerals that are very soft leave a powder on the fingers when handled. Others that are a little harder may be rubbed on a white stone, or, better still, a piece of unglazed porcelain, or the mineral itself may be scratched by a file. All minerals, including the hard ones up to, but excepting the diamond, will yield a streak when rubbed on a "carborundum" hone. Wherever the streak is distinctive it is described under

each monograph. A convenient way of examining the "streak" of a mineral is to powder a little on a clean anvil with a hammer and then to rub the powder with the finger on clean white paper.

Structure.—The structure of minerals, *i.e.*, whether they are crystalline or not, and if so, the system in which they crystallise, is liable to so many variations that, with one or two exceptions, it is much more likely to lead to error than to a positive identification, unless a much more exhaustive study were made of crystallography than workers in the field are likely to devote to it. (For notes on Crystallography *see* Appendix.)

[*]*Hardness.*—A great number of common rocks are *harder* than most metallic ores, but this is not a *fixed rule.* All the gem stones are hard, and their hardness is one of the most useful means of distinguishing them.

The following table of hardness, adopted by most mineralogists, is due to Mohs.

In this table each mineral is hard enough to scratch the one above it in number, talc being taken as the softest and diamond as the hardest:—

1. Talc.
2. Gypsum.
3. Calcite.
4. Fluorspar.
5. Apatite.
6. Orthoclase.
7. Quartz.
8. Topaz.
9. Sapphire.
10. Diamond.

In the absence of a set of these minerals useful information may be yielded by the following tests:—No. 1 and 2 can be scratched by the finger-nail, No. 3 is scratched by a copper coin, No. 4 scratches a copper coin, 5 and 6 are scratched by a good knife-blade, 7 and 8 will scratch a knife-blade. No. 10, diamond, of course, scratches everything.

Blow-pipe Tests.—The various blow-pipe tests may next be performed—namely, heating on charcoal, (1) alone, (2) with carbonate of soda, (3) with potassium cyanide, the borax bead reactions, and the reactions in the open and closed tubes, and the flame-coloration tests.

Wet Tests.—The behaviour of the various minerals with water, hydrochloric acid and aqua-regia, is given in the monographs on each mineral.

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[*] For testing the hardness of supposed gem stones it is convenient to carry a small case containing a piece of the four hardest of the series mounted in holders, namely, Quartz (7), Topaz (8), Sapphire (9), and Diamond (10). Such cases are obtainable from most chemical apparatus dealers.

When minerals are found that are unaffected by aqua-regia, they may generally be decomposed by fusion with potassium and sodium carbonates with a little nitrate of potash (fusion mixture), or by fusion with sodium peroxide.

It must be repeated here that, *at any rate as far as blow-pipe tests are concerned, small quantities of important minerals mixed with larger quantities of the commoner heavy metals would not afford evidence of their presence, without a preliminary concentration.*

Thus iron pyrites might contain a highly payable quantity of gold, or galena might contain a great deal of silver, but neither of these precious metals would be detected by ordinary blow-pipe tests. The proper means to adopt for their recognition will be found under "Gold" and "Silver."

BLOW-PIPE TESTS.

A very considerable proportion of the commercial minerals will afford some kind of distinctive reaction when heated either alone or in company with a suitable reagent. Some of them when suitably treated yield beads of the metal they contain, others yield characteristic incrustations, or volatile products, or impart a colour to flame, or melt or swell up or afford some other indication of their composition.

For example the "noble" metals are reduced to the metallic state by heat alone without fluxes, others which are liable to oxidation require either to be in contact with a reducing agent or a flux. Certain others that cannot be reduced owing to their powerful affinity for oxygen yield characteristic colours when treated with a cobalt solution; several of the metals give a characteristic coloration to flame, and several yield glasses of characteristic tints when a minute portion is heated with borax or with microcosmic salt.

The most convenient means of applying the action of a high temperature is by the aid of a blow-pipe, by which the flame from a candle, lamp or from a gas-jet may be raised in intensity and may be applied either with an excess of oxygen (the oxidising flame) or an excess of carbon monoxide and hydrogen (the reducing flame) at will.

The blow-pipe is applied to the flame in such a manner as to produce a pointed flame about an inch long. This flame will be seen to consist of two distinct zones, an inner (the reducing flame), which is bluish, and an outer, which is yellowish (the oxidising flame). The extreme tip of each flame is employed.

An ordinary candle may be employed, or a wax or tallow lamp with a flat wick, or a spirit lamp. If the latter is used

the heat of the flame may be increased by adding 20 per cent. of benzene to the methylated spirit ordinarily used.

Before submitting any mineral to the action of the blow-pipe it should be examined as regards its *colour*, *streak*, *hardness* and apparent *specific gravity*. Then *if the stone appears to be uniform, i.e., to consist entirely of the same material*, a fragment should be heated on charcoal, and the results carefully observed.. If the stone is obviously a mixture, or even if apparently uniform, it is well to powder some of it down and test it in the pan, to see if any separation can be effected by the action of water. [If any of it appears to dissolve, see under "*Minerals Soluble in Water.*"]

If any separation is effected in the pan, treat the concentrate and the lighter portion separately.

The substance most convenient for placing the mineral on while it is being heated is charcoal.

The best charcoal for this purpose is that prepared from pinewood, but other kinds will serve. If the powdered mineral is light and dusty it may be slightly moistened before being ignited. It should be placed in a shallow cavity in the charcoal, which may be made either with the point of a pen-knife or by boring with a sixpence. The mineral should be heated gently, using the oxidising flame and gradually raising the temperature till the full heat is obtained. The mineral may yield a bead of metal, or an incrustation, or communicate a colour to the flame, or give off a visible vapour or a noticeable odour, or it may deflagrate, or may change colour, and the colour may remain changed or return to its previous shade on cooling.

In any case, try the effect of the reducing flame and note the result, and finally mix with carbonate of soda and heat again in the reducing flame.

Try also to reduce some roasted mineral with potassium cyanide, as this powerful reducing agent will cause the mineral to yield a metallic bead or scales if a reducible metal is present.

Metallic beads will not be produced in this way from arsenic, zinc or mercury ores because they are volatile, nor from iron, nickel or cobalt, because the highest temperature of the ordinary blow-pipe is insufficient to fuse them. The three last mentioned will, however, yield metallic masses in which scales of metal can be detected on grinding and washing the mass with water, so as to cause the fragments of charcoal, flux, etc., to be washed away.

Whether the blow-pipe reaction on charcoal has yielded definite results or not, it is well to examine the mineral in the closed tube and in the open tube.

In the closed tube, the action of air is restricted, and the mineral is subjected to a destructive distillation; in the open tube, on the other hand, it is subjected to an oxidising roast.

The various results that may be obtained are detailed below.

The use of the borax bead is to obtain the characteristic coloured glasses that certain metallic oxides yield when fused with borax. Some of the colours vary according as to whether the "bead" is heated in the reducing or the oxidising flame.

The method of using the borax bead is as follows:—

A thin platinum wire is mounted in a handle at one end, the other end is bent so as to form a small loop, this is heated white hot and plunged quickly into powdered borax, and heated again until a small clear glassy bead is formed in the loop. While still hot and soft this bead is quickly brought into contact with a little of the mineral to be tested, which should previously have been roasted in order to expel sulphur, arsenic, and other volatile compounds that might interfere with the reactions it is desired to observe, or damage the platinum wire by forming brittle compounds. Any colour that is observed should be noted, both when the bead is hot and after it has cooled, after exposure to both oxidising and reducing flames separately.

Silica and most silicates are soluble in the melted borax bead, but in the microcosmic bead silica remains to a large extent insoluble and may be seen floating about undissolved, while the metallic bases dissolve.

All the characteristic blow-pipe reactions that serve to identify each particular mineral are included under the separate monographs on the different minerals, but it will be convenient to describe these reactions here for the purpose of reference.

For all tests with the borax bead, the platinum wire is cleaned by making 3 or 4 borax beads with borax only and flicking them off carefully. After flame colouration tests the wire is cleaned by igniting in the oxidizing flame several times, moistening each time with strong hydrochloric acid.

1. *Reduction on Charcoal.*—The following metallic ores yield beads of metals when ignited in the reducing flame before the blow-pipe on charcoal, with carbonate of soda, or with potassium cyanide:—

Lead.—A soft bead, which marks paper and on reheating on a fresh surface of charcoal in the oxidising flame yields an incrustation which is yellow both when hot and cold.

Tin.—A soft bead, which does not mark paper, and on reheating in the oxidising flame forms an incrustation, yellow while hot, white when cold.

Silver.—A harder but malleable bead, which does not mark paper, and dissolves in nitric acid with evolution of red fumes. The solution deposits a bright coating of silver on a clean copper coin.

Gold.—A bright yellow bead, soft, insoluble in nitric or hydrochloric acids, but soluble in aqua-regia.

Copper.—A malleable bead, red internally, but usually with a black coating of oxide. It dissolves in nitric acid, giving off red fumes and producing a greenish-blue solution.

Bismuth.—A brittle bead, which, on reheating in the oxidising flame on a fresh surface of charcoal, produces an incrustation which is orange while hot and yellow when cold.

A small quantity of sulphur and potassium iodide mixed with a little of the original ore will give a red incrustation when heated sufficiently.

Antimony.—A brittle bead, which, on reheating in the oxidising flame, produces an incrustation near the assay which is white both when hot and cold. If the blast be suspended the fluid bead gives off opaque white fumes, which deposit on the charcoal and finally upon the cooled bead of metal.

Iron, Nickel, and Cobalt are not reduced to beads, as the highest temperature of the blow-pipe is insufficient to melt them. They are, however, reduced to semi-metallic scales, which are visible when the mass is ground with water and the fragments of charcoal, flux, etc., washed away.

In the case of these three metals the metallic scales are attractable by the magnet to a greater or less degree.

NOTE.—*It should clearly be understood that these reactions are only to be expected when the mineral under examination is rich, i.e., is not accompanied by too much earthy matter or gangue. Thus it would very seldom happen that gold or silver ores (particularly the former) would be found sufficiently rich to yield visible metallic beads from the small quantity that can be operated upon before the blow-pipe; so that while a positive reaction is of definite value, the fact that a metallic bead is not found must never be taken as positive proof of the absence of metals which would appear in this group had they been present in greater quantity. For example, a cupful of gold-bearing quartz which contained in the aggregate gold to the size of a pin's head could not possibly be recognised at all before the blow-pipe unless it had been carefully panned down first, and even then, if a little pyrites were present, it would probably be missed; but such an ore as this would probably contain two or more ounces of gold to the ton, and would be a very valuable one. Silver chloride, again, may be and*

generally is disseminated throughout a considerable quantity of gangue, and cannot be concentrated by panning. In both these cases, and whenever the presence of gold or silver is possible, the only way to satisfactorily prove its presence or absence is to fuse a considerable quantity (say not less than 50 grams) with lead or litharge and suitable fluxes, as described under "Gold."

2. *Test with Cobalt Solution.*—A fresh portion of the mineral is roasted before the blow-pipe on a clean piece of charcoal in the oxidising flame. If there is no incrustation on the charcoal, but the mineral is grey or white to start with, or becomes white after ignition, it may be a compound of aluminium, magnesium, or zinc. Moisten the ignited mineral with a drop of cobalt solution and re-ignite. Aluminium compounds will become blue,* magnesia compounds a faint pink,* and zinc compounds a dull green. Calcium, barium, and strontium compounds will be detected by the flame reactions given below.

A coloured residue may indicate iron, copper, nickel, cobalt, chromium or manganese (*see* borax bead reactions and special tests under the monographs on these metals).

3. *Flame Colorations.*—If the mineral when ignited colours the flame violet, potassium is probably present; if red,† strontium or calcium; if yellow, sodium; if yellowish-green, barium; a pale greenish-blue, antimony; pale blue, arsenic or lead; green, copper or boric acid. Borates must be treated with Turner's mixture. Phosphates will yield a blue coloration, but must first be moistened with sulphuric acid.

The experiment should be repeated, using a fresh portion of mineral previously moistened with hydrochloric acid. Most chlorides are volatile, and hence any metals that communicate a colour to flame will be more readily detected after moistening with hydrochloric acid. This will in many cases intensify the flame-colours, some of which are difficult to obtain when the minerals are heated alone. Copper salts give a green coloration, except copper chloride, which gives a blue colour.

4. *Closed Tube.*—A little of the mineral, roughly ground and gently dried, is ignited in a small hard glass tube closed at one end.

Substances containing combined water will give off steam which condenses in the cool portion of the tube. In the case of certain minerals this water will have an acid reaction which may be tested for with blue litmus paper. If the mineral

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* The mineral must be finely ground, and unless fairly free from other substances the colour will be difficult to recognise.

† Lithium has been omitted here, as the crimson flame is not usually obtainable unless Turner's mixture (described under "Lithium") is employed.

contained ammonia or nitrogen some ammonia would be evolved. In the case of ammonia, test with red litmus; frequently, however, ammonia is driven off in combination with an acid, in this case a fresh portion should be mixed with soda, when free ammonia will be evolved. A black sublimate or mirror may be due to arsenic, antimony, mercury, or tellurium. A white sublimate may be due to arsenic or antimony. A reddish liquid sublimate, turning yellow and becoming solid on cooling, is sulphur. A reddish sublimate is probably sulphide of arsenic.

5. *Open Tube.*—A fresh quantity of mineral is ignited in a similar tube, open at both ends. Sulphides will give off sulphurous acid gas recognisable by its smell. Arsenical compounds yield a smell of garlic. A white sublimate is given by arsenic, away from the assay and on the top of the tube, it is easily driven away by heat. Antimony gives a white streak in bottom of tube, not easily driven. Lead gives a small streak difficult to drive away. Tellurium gives a white sublimate, which melts into colourless drops on strong heating.

6. *Borax Bead Tests.*—A very small quantity of the mineral, previously roasted, is fused with a borax bead first in the oxidising and then in the reducing flame. The following are the commoner metals that may be recognised in this way. The colours given are those which are observable after the bead has cooled.

	Oxidising Flame.	*Reducing Flame.*
Chromium	green	green
Cobalt	blue	blue
Copper	greenish-blue	red and opaque
Iron	yellow	bottle green
Manganese	purple	colourless
Nickel	reddish-brown	colourless and dirty opaque

Some of the rarer elements will produce characteristic colours when fairly pure, but as they usually occur mixed with commoner metals the results may be misleading, and the borax bead test should only be applied after the metal sought for has been to some extent separated and purified. In all cases where this test yields useful information it is included under the monographs of the metals and minerals.

Systematic Method for recognising all Metallic Ores and distinguishing them from useless Rocks, etc.—The reasons for adopting the following system of grouping according to colour

has already been explained in the introduction, but if in any case the reader feels unable to assign any particular stone that he may wish to test to any of the colour groups, he should proceed to examine it by the blow-pipe tests and wet tests; these will give him sufficient indication to enable him to compare the characters of the stone he is examining with the details given in these tables. Some preliminary practice with fifty or sixty known minerals will greatly assist him to recognise any ores he may discover, and before starting work in the field he should practice the reactions referred to and should visit a museum and verify for himself the details given as to the *appearance* of the ores described in the following pages.

Where gold and silver are being sought for it is of the highest importance to be able to make quantitative assays on the spot, even if the degree of accuracy obtainable in the field is not so great as can be obtained in a well-fitted laboratory. It will readily be recognised that experience is absolutely essential before any reliance can be placed on the results and, therefore, if the reader has not had practical instruction he should endeavour to obtain such from a qualified assayer, or if this is impossible he should practise on ores of known value and should not place too much reliance on his own results until he has had his results confirmed by a skilled assayer.

In the following colour-classification all the ordinary commercial minerals are described.

They are divided into two groups, first those which *have not* metallic lustre, and secondly those that *have* metallic lustre. The first group is further divided into seven sections and the second into two according to colour.

Minerals WITHOUT *Metallic Lustre:—*

1. *Brown*, of various shades including brownish-red, brownish-black, and brownish-yellow.
2. *Black*, including certain minerals with semi-metallic lustre.
3. *Red*, including reddish-brown, reddish-yellow, and rose-pink.
4. *Yellow*, including yellowish-brown, yellowish-green, and amber-coloured.
5. *Green*, including greenish-blue and greenish-yellow.
6. *Blue*, including light and dark blue, amethystine, and purple.
7. *White*, including colourless minerals and faint shades of various colours.

Minerals WITH *Metallic Lustre*:—

1. Metallic lustre with a tinge of yellow.
2. Metallic lustre with no tinge of yellow, *i.e.*, tin-white, silver-white, lead-grey, and iron black.

PRECIOUS STONES.—The prospector should keep a careful look-out for all gem stones. In the event of his finding any stones hard enough to scratch quartz, that is to say, of a hardness equal to or above 7·0 in the scale of hardness, and which are more or less transparent or translucent, he should preserve them for further examination, after carefully noting the locality in which he found them.

The test of hardness may be applied in the field by carrying a small case containing the four gems representing the four stones highest in the scale of hardness, mounted in little holders after the fashion of a glazier's diamond, namely:—

Diamond	(10)	Topaz	(8)
Sapphire	(9)	Quartz	(7)

There are also a certain number of gem stones slightly below 7 in hardness which possess a commercial value. They will all be found mentioned in the respective colour groupings, but a short table is also given here for the sake of convenience.

A colourless, more or less transparent stone, may be:—

Diamond	hardness	10
Beryl (Aquamarine)	„	7·5–8·0
Phenakite	„	7·5
Moonstone	„	6·0
Precious Opal (iridescent)	„	5·5–6·5
Sphene	„	5·4

A red stone, more or less transparent, may be:—

Ruby	hardness	8·5–9·0
Asteria or Star-stone	„	8·5–9·0
Spinel	„	8·0
Tourmaline	„	7·0–7·5
Garnet	„	6·5–7·5
Diamond (very rare)	„	10·0
Fluor-spar	„	4·0

A green stone, more or less transparent, may be:—

Diamond (rare)	hardness	10·0
Oriental Emerald	„	9·0
Spinel	„	8·0
Tourmaline	„	7·0–7·5
Garnet	„	6·5–7·5
Peridot or Olivine	„	6·0–7·0
Emerald	„	7·5–8·0

A green stone, etc.—*continued.*

Beryl	hardness	7·5–8·0
Euclase (bluish green)	„	7·5
Zircon	„	7·5
Chrysoberyl	„	8·5
Alexandrite	„	8·5
Cat's-eye	„	8·5
Spodumene	„	6·5–7·0
Hiddenite	„	6·5–7·0
Epidote	„	6·0–7·0
Jade	„	6·5
Fluor-spar	„	4·0

A blue stone, more or less transparent, may be:—

Diamond (very rare)	hardness	10·0
Sapphire	„	9·0
Asteria	„	9·0
Spinel	„	8·0
Tourmaline	„	7·0–7·5
Beryl (Aquamarine)	„	7·5–8·0
Moonstone (bluish white)	„	6·0
Turquoise (blue but opaque)	„	6·0
Fluor-spar	„	4·0

A yellow stone, more or less transparent, may be:—

Diamond	hardness	10·0
Oriental Topaz	„	9·0
Quartz-Topaz	„	8·0–7·0
Tourmaline	„	7·0–7·5
Chrysolite	„	6·0–7·0
Beryl	„	7·5–8·0
Phenakite	„	7·5
Zircon	„	7·5
Chrysoberyl	„	8·5
Spodumene	„	6·5–7·0
Sphene	„	5
Cairngorm	„	7·0
Crocidolite	„	7·0
Epidote	„	6·0–7·0
Fluor-spar	„	4·0

A brown stone, more or less transparent, may be:—

Diamond	hardness	10·0
Jargoon	„	7·5
Quartz-Topaz	„	7·0
Topaz	„	8·0
Tourmaline	„	7·0–7·5
Chrysoberyl	„	8·5

A purple stone, more or less transparent, may be:—

Asteria	hardness	9·0
Amethyst	„	7·0
Axinite	„	6·5–7·0
Fluor-spar	„	4·0
Spinel	„	8·0

A pink stone, more or less transparent, may be:—

Diamond (very rare)	hardness	10·0
Ruby	„	8·5–9·0
Spinel	„	8·0
Topaz	„	8·0
Tourmaline	„	7·0–7·5
Garnet	„	6·5–7·5
Kunzite	„	6·5–7·0
Quartz	„	7·0
Fluor-spar	„	4·0

Further details as regards the specific gravity, etc., and the localities in which the various gem stones have been discovered, are given in the various colour-groups under which they are described.

In view of the fact that the identification of precious stones is difficult, and their valuation almost impossible to prospectors in the field, I have arranged with two well-known experts to examine any stones sent to me for identification and valuation. Such samples must be sent by registered post, addressed to me care of THE MINING JOURNAL, 46, Queen Victoria Street, London.

It is quite possible that some of the stones at present used in jewellery, and which are now of comparatively low value, may rise in value owing to the caprices of fashion, or again stones that at present have no commercial value, and are not used at all, may become marketable.

For these reasons it is advisable for the prospector to keep a look-out for any stones that have a hardness above (or not much below) 7·0, bearing in mind that many of the stones that are commercially valuable, even at the present time, do not, in the rough state, present a very attractive appearance, and might be discarded for this reason.

Identification of Precious Stones.—Although the colour of a precious stone is of the greatest importance with regard to its commercial value, it is unreliable as a proof of identity. Correct hardness, specific gravity, and transparency are the most important and the most easily ascertained proofs. The various optical properties of gems may be ascertained by means of more or less simple instruments obtainable for the purpose.

The most useful of these is the dichroiscope. This instrument furnishes a most convenient and easy means of distinguishing coloured gems which crystallise in the cubic system from those belonging to the five other systems of crystallisation. The test can be applied quickly to any doubtful specimen, whether in the rough or cut state, with equally satisfactory results.

A full and detailed account of the recognition of gems will be found in "The Gem-Cutter's Craft," by Leopold Claremont, and in "Precious Stones," by Dr. Max Bauer (*see* Appendix), where a short notice of these books is given.

BROWN MINERALS.*

MANY of the minerals, which if pure would be *white*, are tinted brown by oxide of iron. For instance, the variable mixture known as ordinary earth is usually brown, and many common compounds of silica are brown (also owing to the presence of iron).

The characters of these common brown rocks are given under this section in order to contrast them with the ores and minerals of commercial value.

At the end of this colour-section certain minerals are mentioned which are occasionally brown, but which, being *generally* of other colours, are more fully described under the colours they usually exhibit.

Earth.—To examine "alluvial," that is, earth which has been formed by the disintegration of rocks, and may have been conveyed some distance and deposited by water, it is customary either to sink pits from the surface to the bottom (*i.e.*, the rock), or to bore to "bottom."

The contents of the pits or bores are mixed, quartered down and panned.

The concentrate may contain gold, platinum, osmiridium, cassiterite, magnetite, or precious stones, or fragments of lodestuff of various minerals A detailed list of minerals likely to be found is given in the monograph on the examination of

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* "*Brown.*—This colour characterises some rocks on their fresh fractures, as the variety of ironstone called blackband. A few crystalline rocks have a brown tint from the presence of minerals of that colour, such as varieties of mica and garnet. But it is more particularly on the decomposed surfaces and crusts of rocks that brown tints appear. The iron is there converted into the hydrous peroxide, limonite. Basalt rocks show this change in a most instructive manner. Earthy manganese also gives dark brown to black tints."—(Sir Archibald Geikie, "Outlines of Field Geology.")

"Sands." The examination of the concentrate from "alluvial" should always be carefully made, as, even if the alluvial itself does not contain such minerals as would enable it to be worked with profit, the substances found may lead to the discovery of lodes in its neighbourhood.

As mentioned under "Panning," the ordinary pan holds about 18 lbs. of average earth mixed with gravel or sand—so that 120 pans, roughly, equal one ton, or 160, roughly, equal one cubic yard.

The lower part of the earthy layer in a trial-pit or bore is usually termed the "wash," and consists largely of gravel, and is often much richer in mineral than the upper or earthy portion. Particular care must therefore be taken to get the proper proportionate amount of this material in sampling a pit or bore.

Many common rocks and stones are brown. They are often compounds of silica with aluminium, calcium or magnesium, or the alkalies, the colour usually being due to small quantities of iron.

Their *colour* varies through all shades of brown. Their specific gravity is low, being from about 2·0 to 2·5 or 3·0, whereas most metallic ores are 4·0 or over. Their *lustre* is never metallic, but may be vitreous, or they may be dull or earthy, and have no lustre at all.

They may be hard or soft, but the majority are distinctly *harder* than the majority of metallic ores.

They may be massive and of an amorphous nature, or may be distinctly crystalline. Their streak is usually lighter than their original colour, sometimes it is nearly colourless.

Before the blow-pipe they may change colour or occasionally melt, but yield no incrustation and no metallic beads, and no reaction in the borax bead (except possibly the reaction indicating iron). Heated in the closed tube or open tube, no reaction is obtained except possibly that water is given off.

Treated with hydrochloric acid most of them are unaffected, except that some become lighter in colour, iron passing into solution and yielding a yellowish tint to the acid. Some, however, are decomposed, leaving silica in a gelatinous or powdery condition.

The majority of the siliceous rocks and stones that behave as above have no commercial value and are mentioned here with a view of enabling the reader to contrast the *negative* reactions which they yield with the *positive* reactions yielded by the metallic ores. It must, however, be remembered that small quantities of the useful minerals may be disseminated in them, and therefore it is often advisable to pan a rock or stone, whether any mineral can be seen in it or not.

Iron Ores.—*Limonite* or Brown Hæmatite, Bog Iron Ore, essentially Hydrated Ferric Oxide with Earthy Impurities. [Hæmatite is described under "Red Minerals."]—The colour varies through most shades of brown verging to yellow. The lustre is sometimes silky, but often dull. The hardness is about 3·5, except in the case of bog iron ore, which is softer.

The streak is yellow or brown; specific gravity 3·5 to 4. Heated before the blow-pipe, water is given off and the specimen becomes darker in colour, and finally reddish when cold.

Strongly heated in the reducing flame with carbonate of soda or potassium cyanide, a mass is obtained from which a metallic powder can be separated by washing. This powder consists of metallic iron, and is attracted by the hand-magnet. Treated with warm hydrochloric acid, all forms of limonite dissolve, leaving as a residue any siliceous or clayey matter which may be present.

Göthite has much the same composition as limonite. Göthite is more fibrous than limonite.

Siderite, also known as "White Iron," Chalybite, Spathic Iron, Carbonate of Iron.—The colour varies from a very light brown through all shades to dark brown. The lustre is vitreous, occasionally somewhat pearly, never metallic.

The hardness is only moderate, it can be scratched with a knife; specific gravity about 3·8.

It is not magnetic before heating. On heating in the closed tube it turns black and is then attracted by the hand-magnet. It gives the reactions for iron in the borax-bead. Ignited on charcoal it turns reddish-brown, and when strongly ignited it can be fused. It is not soluble in cold hydrochloric acid, but dissolves on heating with liberation of carbonic acid gas. It is sometimes mistaken for cassiterite, but it is readily distinguished by its solubility in hot hydrochloric acid.

Phosphatic Rock, Osteolite (altered Apatite), Earthy Phosphate, Coprolites, Impure Calcium Phosphate.—Phosphatic rock is usually light brown, white, grey, yellowish-brown, or dark brown. It is, as a rule, structureless* and soft. Its specific gravity is about 3·0. Before the blow-pipe it is unchanged and does not melt. It may turn lighter through the burning off of organic impurities, or browner from the oxidation of iron compounds. Ignited on a platinum wire with a drop of strong sulphuric acid, a bluish-green flame is produced (phosphorus), and similarly ignited with hydrochloric acid a brick-red colour (calcium).

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* The crystallised variety is usually known as Apatite, see under "White Minerals."

All phosphates ignited in a tube with a little magnesium or aluminium foil and cooled and moistened with water emit a peculiar disagreeable smell (phosphoretted hydrogen).

All phosphates of calcium are soluble in hydrochloric acid and in nitric acid. If there is any effervescence a carbonate is present. A solution of ammonium molybdate added to a nitric acid solution of a phosphate produces a bright yellow precipitate. The reaction occurs best when the mixture is moderately acid and heated to about 70° C. This reaction may be employed conveniently to estimate the quantity of phosphoric acid in a sample of a native phosphate (*see* under "Phosphorus").

Monazite Sand.—Essentially a compound of cerium, lanthanum and didymium phosphates with thorium* silicate, and possibly other metals of the rare earths. It may occur as a rock, but is much more frequently found in the form of sand, either by itself or mixed with ordinary sand or gravel. As monazite has a gravity of about 5·0, ordinary sand can be panned away.

The predominant colour of the separate grains is yellow or pink with a lesser number of brown and black particles, and the general appearance of the sand is reddish-brown. The grains are more or less transparent with a resinous or vitreous lustre. It is sometimes accompanied by ilmenite and magnetite, the latter may be removed by a hand-magnet, and the former by an electro-magnet.

Ignited before the blow-pipe monazite does not melt but turns greyish. Moistened with sulphuric acid and ignited on a platinum wire it affords the reaction for phosphoric acid (a bluish-green flame coloration).

The mineral is not attacked by dilute aqua-regia, and, therefore any sample of sand that is to be tested for monazite may be purified by treatment with a mixture of hydrochloric and nitric acids. If after such purification it is very finely ground and evaporated to dryness two or three times with strong sulphuric acid it is decomposed. On taking up with water, a few drops allowed to evaporate spontaneously on a slip of glass will yield characteristic crystals of cerium phosphate.

These crystals are seen well under an inch objective and will consist of either double ball-shaped clusters of radiating needles or minute isolated crystals, shaped like cucumber seeds. According to Dr. Ohly,† this test can be used on a single grain of monazite sand and is conclusive taken in conjunction with the phosphate reaction which is performed

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* It is valued for the thorium it contains.

† "Rare Metals," by Dr. Ohly.

by treating a drop or two of the watery extract obtained on adding water to some of the sample previously evaporated with strong sulphuric acid, filtering and testing with ammonium molybdate in company with a little nitric acid. A yellow, amorphous precipitate shows the presence of phosphoric acid.

For the method for separating the rare earths as a group, *see* under "Thorium."

Guano.—A mixture of phosphate of calcium with ammonia salts and organic matter.

The colour is brown, reddish-yellow, yellowish, etc. It is usually earthy and soft. The specific gravity is about 2·5.

Heated on a shovel or before the blow-pipe it is partly volatilised, and a white fume of ammonia salts is given off. Warmed with an alkali the characteristic odour of ammonia is evolved.

Guano is often partly soluble in water, and should be almost entirely soluble in nitric acid, with little or no effervescence. The value of guano is based upon the percentages of nitrogen and phosphoric acid it contains.

The ammonia present may be estimated by distilling a weighed quantity with a caustic alkali solution, and receiving the distillate into standard acid. The phosphate present can be estimated by precipitating from the nitric acid solution with ammonium molybdate.

Guano is only likely to be found on unfrequented islands, which are, or have been, the resort of seabirds. A variety of guano produced by the droppings of bats is formed in certain caves in India, Africa, and elsewhere.

[For further information, *see* under "Nitrogen."]

Fuller's Earth, hydrous aluminium silicate, is usually brown, yellowish-brown or greenish-brown. It is soft and can be scratched by the nail. It has a soapy feel to the fingers.

Heated at the highest heat of the blow-pipe it forms an enamel-like glass, which may be greenish (iron).

Treated with hydrochloric acid some iron will go into solution leaving the mineral lighter in colour.

Although very similar in composition to the clays, it does *not* form a plastic mass with water, but is friable and more inclined to fall to pieces.

Heated with a little cobalt solution on charcoal it gives the bluish colour characteristic of aluminium compounds.

Ordinary Siliceous Sand is often brown, but as it is more commonly *yellow*, it is described under "Yellow Minerals."

Certain other minerals besides those enumerated may be brown, for example:

Most Jasper is brownish-red.
Some Garnet.
Some Blende.
Some Rutile.
Some Cassiterite when massive, almost all Cassiterite is brown in powder.
Some Zircon is reddish-brown.
Some Cinnabar.
Some Tourmaline is yellowish-brown.
Some kinds of quartz are brownish-black.
Some Cuprite is brownish-red and so is some Hematite, but as the two latter are more often red, they are placed among the red minerals.
Chocolite (a variety of Garnierite) is brown.
Some Chrysoberyl is brown.
Some Topaz is brown.
Some Demantoid is brown.

BLACK MINERALS.[*]

The following are described in this section:—

Blende.
Pitchblende.
Wolfram.
Melaconite or Tenorite.
Tantalite.
Pyrolusite.
Magnetite.
Cassiterite.
Chromite.
Thorite.
Ilmenite or titaniferous iron ore.
Tourmaline.
Graphite.
Coal.
Asphalt and Bitumen.
Boart.
Black Opal (*see* Opal).

Pyrargyrite is a very dark red, approaching black, but it is red in thin fragments and in powder, and is described under "Red Minerals."

Coal.—The appearance of coal and its combustibility afford ready means for its identification.

The various types of coal and their uses are discussed under the article on "Carbon."

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[*] "*Black.* Many carbonaceous rocks are black. Coals may be distinguished by their lightness, texture, and combustion. Clays or shales, rendered black by the vegetable matters they contain, may be recognised by their weight, streak, and their turning white, but retaining their shape when strongly heated. But heavy black rocks abound in which there is no trace of carbon. These very generally contain a considerable amount of iron, either in the form of magnetite, ilmenite, or other related oxide, or in that of some black ferruginous material, such as hornblende. Such rocks are apt to weather with a brown or yellow crust, owing to the conversion of the iron into the bydrous peroxide."—(Sir Archibald Geikie, "Outlines of Field Geology.")

If an outcrop of coal is discovered, a trial pit should be sunk, and a sample of at least 1 cwt. should be taken from a cut across the seam, some feet from the surface, as the weathered portions that have been exposed to the atmosphere would not fairly represent the quality of the deposit.

The ash of certain coals has been found to contain vanadium, and it would therefore be advisable to test any new discovery for this metal, which is likely to be in considerable demand.

For information on Coal, *see* under the monograph on "Carbon."

Asphalt.—Deposits of asphalt are worked to a large extent in Trinidad and in other parts of the world.

Its appearance, combustibility, and consistence afford sufficient means for its recognition. While some deposits are found nearly pure, it is also found in grains or filling cavities and joints in sandstone or limestone. On heating a specimen of bituminous rock, the bitumen exudes, and catches fire. One method of extraction is to heat the rock in cylinders, when a certain proportion of the bitumen will drain out. This is a wasteful plan, and about two-thirds of the total quantity is lost in the process.

Any deposit of workable size would deserve careful attention.

Black Iron Sand, Magnetic Iron Oxide.—The colour is iron black, and the streak is the same. Lustre either dull or slightly metallic. Hard, specific gravity about 5·0, it is nearly infusible before the blow-pipe.

It gives the reactions for iron with the borax bead. It is attracted by the magnet. It is soluble in hydrochloric acid on boiling.

Black iron sand is frequently associated with deposits of gold (and sometimes platinum), monazite and cassiterite, and should therefore be carefully examined for these minerals.

Pyrolusite, Manganese Dioxide.—The colour is black, the mineral varies from soft to hard, and is usually structureless and earthy, but sometimes fibrous.

Lustre, sub-metallic or silky; when soft or when powdered it stains the fingers.

The streak is black. There is no visible alteration on ignition on charcoal, but oxygen is given off, which may be recognised by heating the mineral in a closed tube, and introducing a slip of wood with a spark at the end, which will glow more brightly in the oxygen evolved from the mineral.

With borax bead gives amethyst colour in the oxidising flame, which becomes colourless in the reducing flame; if fused with carbonate of soda and nitre, a green mass forms.

When warmed with hydrochloric acid, chlorine, a yellowish-green gas with a suffocating odour, is given off.

Wad and Psilomelane are minerals of somewhat similar nature, but contain water chemically combined.

Wad may contain cobalt, nickel, or copper, and is the result of the decomposition of manganese ores. It is often found in hollows between hills or other low-lying spots.

Blende, "*black jack*," or Sulphide of Zinc.—The colour is usually black or brownish, but it is also reddish or greenish-yellow, light yellow, or nearly colourless and transparent.

The lustre is vitreous or resinous (sometimes semi-metallic) and the streak very pale brown, reddish-brown, or nearly white.

The specific gravity is about 4·0; it is moderately soft.

Heated in the open tube, sulphurous acid gas is given off and a residue of oxide is left.

Heated on charcoal before the blow-pipe, oxide* of zinc is formed with an incrustation, which is yellow when hot and white when cold. If this incrustation is moistened with solution of a cobalt salt and strongly heated the incrustation becomes dull green in colour.

If a stone of blende is placed in a fire, after continued roasting the outside crust assumes a light yellow colour due to the formation of zinc oxide.

Blende is soluble in hydrochloric acid, with evolution of sulphuretted hydrogen.

Blende sometimes carries considerable quantities of silver.

Wolfram, Wolframite, essentially Tungstate of Iron, with varying proportions of Manganese.—The colour of *freshly broken pieces* is black with sub-metallic or sometimes bright adamantine lustre. It generally has a laminated or banded appearance, which is characteristic. Alluvial wolfram,† or pieces of lode-stuff that have been exposed to the air and water for some time, are generally coated with a film of reddish-brown oxide (probably iron oxide) and often have little yellow specks (tungstic ochre) on them.

The streak is a deep brownish-red. The specific gravity is about 7·2, and varies from 7·0 to 7·5.

The borax bead reaction will give the characteristic appearance due to iron and manganese.

Heated before the blow-pipe it will not melt, but decrepitates.

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* The metal, zinc, is not formed in presence of air owing to its great affinity for oxygen.

† The external brownish-red colour of weathered pieces of wolfram is much the same colour as brown hæmatite.

Wolfram is decomposed somewhat in hot hydrochloric acid; when very finely powdered and well boiled in aqua-regia it is decomposed more readily, in any case it takes several hours, and the mineral must be in a *very* fine powder. The iron and manganese dissolve and tungstic acid is left as a yellowish powder. This yellow powder, tungstic acid, gives a colourless bead with microcosmic salt in the oxidising flame, and a blue bead in the reducing flame.

Freshly prepared tungstic acid is easily soluble in ammonia.

Wolfram is *not* attracted by the hand-magnet, but the electro-magnet (being more powerful) is employed to separate it from cassiterite, with which it frequently occurs.

Melaconite or Tenorite, Black Oxide of Copper.—The colour is dull black, and the specific gravity is about 6·0 when pure. It is earthy and soft. The streak is black. Infusible alone before the blow-pipe, but with soda yields a bead of copper. It is unchanged on ignition in the open or closed tube. With the borax bead it gives a greenish-blue bead in the oxidising flame, and a red and opaque bead in the reducing flame.

It is soluble in hot hydrochloric acid, giving a greenish-blue solution which deposits metallic copper on a bright knife blade.

When pure it contains nearly 80 per cent. of copper.

Tantalite, essentially Tantalate of Iron and Manganese with Niobate of Iron and Manganese.—This rare mineral is nearly black if freshly broken, but dark brownish-red on exposed surfaces. It is hard, and the specific gravity may vary from about 6·5 to 7·5 (according to the percentage of tantalum).

The lustre is sub-metallic and the streak a brownish-olive.

Before the blow-pipe it is unaltered, and does not fuse.

It is insoluble in all acids, but can be fused with pure potash when very fine, and the melt extracted in water, from which the tantalic acid is precipitated by most acids. *Note.*—This cannot be relied upon as a method for getting it completely into solution, although it is soluble in hot hydrofluoric acid if *very* finely powdered and given sufficient time.*

Tantalite is not attracted by the hand-magnet. It may be mistaken for cassiterite, wolfram or hæmatite, but would readily be distinguished on the application of tests.†

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* Hydrofluoric acid is a dangerous reagent to deal with, and must be kept in india-rubber bottles, and used in platinum or lead vessels.

† Cassiterite gives a bead of tin on ignition with cyanide; wolfram yields an insoluble yellow residue after prolonged boiling with aquaregia; hæmatite and chalybite dissolve in hydrochloric acid on boiling; ilmenite and tourmaline can be washed away on the pan or vanning shovel by careful re-grinding and washing. If wolfram is present, the concentrate must be *very finely* powdered and boiled for six hours or more with aquaregia; the wolfram is converted into tungstic acid, which is soluble in ammonia.

Cassiterite, Tin Dioxide.*—The colour is usually black or brown, but occasionally is ruby-coloured, amber, and even nearly white; the streak is light grey, or light brown.

It is hard, a crystal cannot be scratched by a knife. The specific gravity is about 6·8 to 7·0. The lustre is never metallic, but either vitreous or adamantine.

Heated in the open or closed tube, there is no reaction.

Heating on charcoal alone, it is difficult to produce a bead of tin, but heated with potassium cyanide on charcoal a bead of tin is easily obtained, which is malleable and does not mark paper.

Treated with hydrochloric acid, or aqua-regia, cassiterite is practically unaffected, but may become rather lighter in colour, owing to removal of iron.

Pure cassiterite contains from 70 to 76 per cent. of tin; dressed tin (from rock) usually about 68 to 70 per cent.

In Cornish tin ores the cassiterite is usually brown or brownish-black. The tint is due to impurities, possibly iron, as pure dioxide of tin is white, and abroad (in Tasmania, for example) grey cassiterite is found, and it may also be light or dark yellow, all shades of brown, to nearly black. Some cassiterite can hardly be distinguished by the eye from blende, but on powdering and panning, cassiterite is generally recognisable by the appearance of the "head" in the pan, and the crystals of cassiterite are harder than those of blende.

Chromite, native Chromate of Iron.—The colour is black, or brownish-black, with more or less dull semi-metallic lustre. The specific gravity is about 4·5, it is hard but brittle. Chromite is unaffected by acids, and is not attracted by a hand-magnet. Tested with a borax bead it gives a green colour in both oxidising and reducing flames. It is decomposed by fusion with caustic alkalis. When pure it contains 68 per cent. of Cr_2O_3, if it contains less than 50 per cent. it has little or no commercial value.

Thorite, Silicate of Thorium with other metals.—The colour is usually orange-yellow or brownish-yellow. Some specimens are nearly black. Thorite contains about 50 to 70 per cent. of thorium and about 18 per cent. of silica.

The lustre of freshly broken pieces is vitreous. Specific gravity is about 5, but varies considerably.

Before the blow-pipe it does not melt. The borax bead tests are not distinctive.

Treated with hydrochloric acid it is decomposed, the silica separating in a gelatinous condition (distinction from cassiterite and wolfram).

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* This ore is seldom found massive, and is usually disseminated in rock or alluvial. Before applying tests it must be concentrated by panning.

The identification of the presence of thorium may be made as in monazite.

Orangite is apparently similar in composition. The colour of orangite is an orange-yellow, or brownish-yellow. (*See also* under "Monazite" and under "Thorium.")

Up to the present thorite has been found chiefly in Ceylon, and in very limited quantities.

Pitchblende,* Uraninite, Oxide of Uranium, usually accompanied by Lead and Iron.—The colour is black, and the lustre is sub-metallic, dull, or pitch-like.

It is heavy, the specific gravity being about 8·0 in crystalline specimens, but in non-crystalline masses it may be from 6·5 to 7·0.

It is hard; the streak is usually greenish-black. Before the blow-pipe it is infusible. It is not attracted by the magnet.

It cannot be tested directly in the borax bead, because the iron and other impurities would prevent the uranium reaction from being observed. *After purifying, as described under "Uranium," the borax bead test can be successfully applied.*

Pitchblende is soluble in nitric acid.

Pitchblende is often accompanied by uranium ochre, which is a yellow incrustation, of an earthy appearance. This is a product of oxidation, and may therefore frequently be seen on pitchblende that has been lying about exposed to the air and the rain. It may also be accompanied by Torbernite and Autunite, Uranochre, etc.

The following method can be employed for the detection of uranium in pitchblende or any uranium mineral. Dissolve in nitric acid. Evaporate to dryness, but do not heat too much. Extract with water and evaporate again. Extract the residue left on evaporation with ether, in which uranium nitrate is soluble. On adding ammonia a yellow precipitate is formed, which turns greenish-black on ignition.

Titanite, Menaccanite, Ilmenite, or Sphene, essentially Titanate of Iron.—The colour is a dull black usually, sometimes with dull sub-metallic lustre.

The specific gravity is about 4·5. It is rather hard.

Before the blow-pipe it does not fuze, and its appearance is unchanged. It is not attracted by the hand-magnet.

It dissolves slowly when boiled in fine powder with hydrochloric acid.

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* Pitchblende is a rare mineral, but on account of its high value all heavy black minerals possessing characters resembling pitchblende should be carefully examined. Pitchblende often contains some thorium.

Titanium may be recognised in this solution by reducing the solution by boiling the acid solution with a piece of zinc or of tin-foil, when a colour ranging from pale violet to pink is produced.

Ilmenite is distinguished from wolfram by its not yielding a yellow residue of tungstic acid on prolonged boiling with aqua-regia.

Titaniferous iron ore has but little commercial value, but when found as a sand is sometimes mistaken for cassiterite or for wolfram.

If ilmenite is fused on foil with bisulphate potash, 8 parts to 1, dissolved in cold water, filtered, and the filtrate added to a quantity of water and boiled, a white precipitate is produced.

**Black Tourmaline*, Schorl, also known as "Cockle"; chiefly Silicate of Iron and Alumina.†—The colour is black or blackish-brown.

The specific gravity is about 3·0.

The lustre is dull to vitreous, never metallic. The streak is nearly colourless. The mineral is fairly hard, often crystalline; it often occurs in striated or needle-shaped tufts.

Before the blow-pipe it swells up and may melt, but with difficulty.

It is not soluble in hydrochloric acid or aquaregia.

It has no commercial value and is described here in order to distinguish it from wolfram, cassiterite and some other minerals to which it is somewhat similar in appearance.

Coloured *transparent* varieties of tourmaline are also met with; Rubellite, red; and Indicolite, blue; and it may be also brown, yellow, white or green. Some of these, when pure and free from flaws, have a value as gems. Like the black variety their streak is nearly colourless.

Graphite.—Plumbago or "Black-lead" is an impure form of carbon. The colour is black with semi-metallic lustre. The streak is black and shining; specific gravity under 2·0. It is very soft, can be scratched by the finger-nail, soils the hands and marks paper. It is unchanged before the blow-pipe, but deflagrates when ignited with a nitrate or chlorate.

Does not dissolve in the borax bead. Insoluble in all acids.

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* In Cornwall and elsewhere the name "Black Ram" is often applied to black minerals or rocks of no value, and these, I think, are usually a dark tourmaline.

† All the tourmalines contain boron, which may be demonstrated by igniting before the blow-pipe, after admixture with Turner's mixture. A green coloration is given to the flame when the mass melts, but the colour only appears for a moment.

Graphite is a good conductor of heat; it feels cold to the hand. Graphite might sometimes be mistaken for molybdenite as far as its naked-eye appearance and softness goes, but molybdenite is recognised by its giving off fumes of sulphurous acid gas when heated in air and an incrustation on charcoal which is yellowish white in the oxidising flame, neither of which are obtained from graphite. It is distinguished from pyrolusite by being unaffected by boiling with hydrochloric acid. Graphite may occur massive, or disseminated through rock.

The value of a deposit of graphite depends very greatly on its purity, and whether the impurities it contains are removable by dressing and treatment.

Boart, *black diamond* or *carbonado* consists of imperfectly crystallised diamond; it is found in Brazil. It is grey or black, translucent to opaque. On account of its hardness it is employed in boring. It resembles ilmenite in appearance, but has a lower specific gravity, and is readily distinguished from it by its far greater hardness.

It cannot be scratched by a file and is unaffected by acids.

It has a high commercial value.

RED MINERALS.

The following minerals are described or referred to under this section :—[*]

Native copper (with metallic lustre when cut or filed).
Hæmatite, brick-red, sometimes crimson (when earthy), but more often iron-grey or almost black.
Erythrine, peach-red.
Lepidolite, pale rose-red.
Zincite (Spartalite), red to orange-red.
Proustite, crimson, in powder or in thin sections.
Pyrargyrite, very dark red, approaching black.
Cinnabar, red to reddish-brown, livery brown to nearly black.
Crocoisite, red, orange-red to nearly black.
Realgar, red to orange.
Cuprite, red to reddish-brown.
Asteria, or star stone.
Ruby.

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[*] "*Red.* The prevailing hue of red rocks varies from a brownish-red to a bright brick-red, and is due to the presence of the peroxide of iron, hæmatite. Such rocks are often mottled with or pass into yellow and brown tints where the iron they contain has been hydrated. These colours are most typically displayed among red sandstones and clay, of which an enormous mass occurs in the Old Red and New Red Sandstone, and in the Trias. Some rocks show a delicate flesh-red tint from the colour of their orthoclase felspar, as in pink granite. Iron is in this case also the pigment."—(Sir A. Geikie.)

Corundum (*see* under Aluminium).
Spinel.
Garnet.
Rutile.
Kunzite.
Ruby tin (*see* under Cassiterite).
Rubellite (*see* under Tourmaline).
Wulfenite, red, orange-red.
Some Jasper is red.

Native Copper.—This is the only metal of a reddish colour.

Its specific gravity is 8·8. It is soft enough to be cut with a knife, and is malleable, that is, it can be hammered out without breaking to pieces.

The streak is copper coloured.

Before the blow-pipe it will tint the flame a bluish-green and melt if strongly heated in the reducing flame. The charcoal support will be coated with red oxide of copper.

Specimens will usually be discoloured by surface oxidation, or stained a greenish colour with copper carbonate.

Nitric acid dissolves copper with vigorous evolution of red fumes, a bluish-green solution being formed.

Native copper almost always contains some silver and often some gold, and should be tested for these metals.

Red Hæmatite, Sesquioxide of Iron.—It is usually dull red, but sometimes crimson; it may also be steel-grey or nearly black.

Its specific gravity when massive is about 5·0, in the earthy varieties it is less.

The streak is red or reddish-brown.

Heated before the blow-pipe it does not melt, but after strong heating on charcoal in the reducing flame with carbonate of soda, magnetic scales are produced.

The borax bead gives the reaction for iron. Hæmatite dissolves when treated with hot strong hydrochloric acid.

The variety known as *micaceous iron ore or specular iron ore,* has a distinct metallic lustre, and is usually in scales which have a greasy feel.

Limonite is practically the same as hæmatite, except that it is brown, and contains water. It is described under "Brown Minerals."

*Erythrine,** peach or rose-red, or "cobalt bloom," is an impure hydrous cobalt arseniate, associated with nickel and iron compounds and sometimes with considerable quantities of silver.

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* A valuable find of this mineral associated with silver was made at Cobalt City, in America, in 1906, the deposit being so extensive as considerably to lower the price of cobalt.

Usually bright red or rose-red, but sometimes grey, usually very soft, earthy, without metallic lustre. The streak is rather paler pink, but when dried is blue, or lavender. The specific gravity is low, about 3·0. Heated before the blow-pipe on charcoal it blackens and gives off arsenious acid and melts, forming a bead of cobalt arsenide. It dissolves in hydrochloric acid, giving a pink solution. If silver is present chloride of silver will be formed, and should be tested for by cupelling* the insoluble residue after filtering the solution.

Zincite, also known as Spartalite, Oxide of Zinc.—The colour is red,† and the streak orange coloured. Hardness moderate.

Lustre more or less adamantine.

Specific gravity about 5·5.

When heated on charcoal before the blow-pipe in the reducing flame it is partly volatilised, and gives the characteristic incrustation of zinc (yellow when hot and white when cold). This incrustation, if moistened with cobalt solution, re-ignited and cooled, shows a dull green colour. In the closed tube it blackens, but becomes red again on cooling.

It is soluble in hydrochloric acid.

Lepidolite or Lithia Mica is a silicate of alumina, lithium and potassium, and fluorine is usually present.

In colour it is usually a faint rose-red or pink, but may also have a bluish-grey or lilac tint, or be light-grey, white or light-yellow. In structure it consists of granular scales. The scaly structure and pearly lustre are characteristic. The streak is colourless.

It is not hard, and can be easily scratched by a knife. The specific gravity is under 3·0.

Before the blow-pipe it melts, yielding a bright purple-red tint to the flame at the moment of fusion. This is better seen by heating the powdered ore on a platinum wire moistened with strong hydrochloric acid.

The mineral is not easily attacked by acids, but after powdering and roasting it can be decomposed by prolonged treatment with either hydrochloric or sulphuric acids, and the silica that separates is gelatinous.

It contains from 2 to 5 per cent. of lithia.

"*Ruby Silver Ores.*"—*Proustite*, sulphide of silver and of arsenic, is crimson-red in colour; it is often somewhat translucent. It is heavy, the specific gravity when pure about 5·5.

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* The method of cupellation is described under "Gold."

† Pure zinc oxide is white. Zincite is said usually to contain some manganese, which is supposed to cause the red colour. This ore is not a common one and is only found in one or two localities.

The streak is red. With carbonate of soda on charcoal before the blow-pipe it yields a bead of silver, fumes of sulphurous acid gas and of white arsenic being given off. Heated in the open tube, a sublimate of white arsenic (octohedral crystals, visible with a strong lens) is obtained and sulphurous acid fumes. It is decomposed by nitric acid, but not by hydrochloric acid.

Pyrargyrite, Sulphide of Silver and of Antimony.—The mineral is usually very deep red, red, reddish-black or black, but the streak is always red. It is soft and readily scratched by a copper coin. Sometimes partly translucent. On charcoal before the blow-pipe with carbonate of soda a bead of silver is obtained and a white incrustation and white fumes of oxide of antimony. In the open tube a white sublimate of antimony is obtained and fumes of sulphurous acid gas. It is decomposed by nitric but not by hydrochloric acid.

Crocoisite (or Crocoite), Chromate of Lead.*—Red, or orange-red to nearly black, with a somewhat vitreous lustre. The specific gravity is high, about 6·0. It is soft enough to be scratched by a copper coin; the streak is yellow, or orange coloured. Before the blow-pipe on charcoal it yields metallic lead, and incrustations of the oxide of lead and chromium. In a closed tube it blackens, but is not decomposed and returns to its normal colour when cooled.

It gives the green chromium reaction in the borax bead. It dissolves in hydrochloric acid on boiling, giving a green solution, from which lead chloride is precipitated on cooling.

Realgar, Arsenic Sulphide.—Red or orange coloured; vitreous lustre, more or less transparent or translucent. On ignition fumes of sulphurous acid gas and of white arsenic are evolved.

It is decomposed by nitric acid, but not by hydrochloric.

Realgar is only red when freshly broken; on exposure to air it is gradually converted into the yellow sulphide, Orpiment.

Cinnabar, sulphide of mercury, varies from bright red to reddish-brown,† or livery brown to nearly black.

If massive, its specific gravity at once attracts attention,‡ being about 9. When massive, it is often crystalline and partly

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* This is a rare mineral, and does not occur in workable quantity. It would not be found on the surface of the ground as the crystals disintegrate and decompose in presence of water; finely crystallised specimens have a value for collectors.

† The name "hepatic" or "earthy cinnabar" is applied to the dark-coloured varieties.

‡ "Almadenite" is a massive chocolate-brown variety from Almaden (in Spain).

translucent with a vitreous lustre. It is soft and can be cut with a knife. The streak is bright red.

It is entirely volatilised on heating before the blow-pipe, if the sample is pure. Heated in a closed tube a black sublimate of mercuric sulphide is produced. If a specimen is supposed to contain cinnabar, concentrate some in the pan and heat some of the dried concentrate with half its weight of iron filings in a test-tube. A sample of cinnabar will yield a sublimate of mercury in minute globules on the cooler part of the tube. In the open tube the free access of air decomposes the sulphide of mercury into sulphurous acid gas and metallic mercury which is deposited as a sublimate on the cooler part of the tube. Cinnabar is insoluble in hydrochloric acid, but is decomposed by aquaregia. The insolubility of cinnabar in hot hydrochloric acid distinguishes it from hæmatite. A simple test for the recognition of cinnabar is the following. Dissolve the mineral in aqua-regia, place two or three drops of the solution on a gold coin and place the point of a knife in a drop of liquid so that the point rests on the coin. If mercury is present, enough will be reduced to yield a whitish stain on the coin. (The stain vanishes again on heating and the coin is left uninjured.)

Cuprite,[*] or red oxide of copper, varies from red to reddish-brown. Its lustre is adamantine, sometimes slightly transparent. It blackens on exposure to light. It is usually crystalline (octohedral). It is moderately hard, under 4·0 and brittle. The specific gravity is high, about 6. The streak is brownish-red. Before the blow-pipe on charcoal it first becomes black, and on strong ignition in the reducing flame yields a bead of copper, which is more readily obtained by igniting with carbonate of soda.

In the borax bead it gives a greenish-blue colour in the oxidising flame and in the reducing flame becomes dull red and opaque. It is soluble in hydrochloric acid, giving a greenish-blue solution that deposits metallic colour on a steel knife-blade.

When pure, contains 88 per cent. of copper.

Tile-ore is an impure, earthy variety.

Chalcotrichite.—This is a cochineal-red variety, occurring in delicate, needle-like crystals; it is of rare occurrence.

Cassiterite is occasionally found of a reddish colour, semi-transparent, and is known as "ruby" tin. Its specific gravity and all its other characters are similar to the ordinary blackish-brown variety. In the opinion of the author it is very probable that "ruby" tin is the ordinary black or brown cassiterite which

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[*] This ore of copper is uncommon, but as it is a very valuable one, any discovery would be of great importance.

has been exposed to heat (by bush fires, etc.), as he has only found it in alluvial or in surface stones. The ordinary black or brown cassiterite usually becomes of a redder colour after ignition.

The author would be interested to hear the experience of others on this point.

Garnet, a well-known gem stone. It occurs red, brown, and violet in which colours it is of small value; the green variety, generally called by jewellers olivine, is of considerable value. There is also a yellowish-brown variety called essonite, which is also marketable. Garnets are found in India, Brazil, Ceylon, Australia, South Africa, etc. The hardness is 6·5—7·5 and the specific gravity 3·5—4·3.

See "Precious Stones," by Dr. Max Bauer, page 345.

Spinel.—This mineral occurs in nearly all colours; when transparent it is used as a gem. The red variety which somewhat resembles the ruby is of considerable value. It is found in the form of octahedral crystals which are often perfect in shape. Hardness, 8; specific gravity, 3·5—3·6; lustre, vitreous; these stones are found in India, Brazil, Siam, Burma, Afghanistan and New York, generally embedded in granular limestone, gneiss or volcanic rocks. Chemical composition—alumina, 71·99; magnesia, 28·01.

Ruby.—The ruby is always red, but varies considerably in the shade of red. The ruby consists almost entirely (about 98 per cent.) of alumina.

Rubies are usually found in the gravels forming the beds of modern or ancient rivers.

The hardness is from 8·5 to 9, so that it is a little less hard than the diamond.

The specific gravity varies somewhat, being from 3·9 to 4·2.* The lustre is bright and vitreous.

Before the blow-pipe the ruby does not melt, but a fragment treated in a borax bead will dissolve to a clear glass.

The ruby is unaffected by all acids.

Rubies are at present found in Burma, Ceylon, Siam and Pegu.

See "The Gem-Cutter's Craft," by Leopold Claremont, page 118.

Star-Stone or *Asteria.*—An asteroid variety of corundum; it occurs red, blue, and grey; found in conjunction with rubies and sapphires in Burma, Cashmere, and Ceylon. It is valuable as a gem stone.

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* **See footnote to monograph on the Diamond.**

Kunzite.—A pink or lilac coloured variety of spodumene only recently introduced into jewellery; phosphorescent after exposure to the "X" rays, or radium.

YELLOW MINERALS.*

THE following are included in this group:—

Ordinary Sand and Sandstone.
"Gossan."
Bismuth Oxide and Carbonate.
Clay, yellow.
Ochre, yellow.
Uraconite.
Wolframine or Tungstic Ochre.
Iodargyrite and Bromargyrite.
Molybdite, Molybdic Ochre.
Wulfenite, Molybdate of Lead.
"Rosin Tin."
Topaz.
Amber.
Realgar.
Orpiment.
Native Sulphur.
Vanadinite.
Sphalerite (blende).
Bauxite.
Carnotite.

Some Sapphire is yellow.
,, Chrysolite ,,
,, Jasper ,,
,, Beryl ,,
Some Chrysoberyl is yellow.
,, Tourmaline ,,
,, Garnet (Essonite) is yellow.

Sand.—The ordinary sand of the seashore is yellowish, and consists principally of quartz coloured with oxide of iron; some sea-sands contain 45 per cent. of lime produced by grinding up of shells. The useful minerals likely to be found associated with such sand are obviously only those which by reason of their insolubility in water, particularly also in water charged by chlorides, and their indifference to atmospheric action are able to resist decomposition.

For these reasons it is highly unlikely that such a substance as horn silver would be found in sea-sand (as it is soluble in a solution of sodium chloride), and as most of the compounds of the heavy metals are oxidised and altered by exposure very few of them are likely to be found.

The following metals and minerals of commercial utility may be found in sands, gold and platinum (and allied metals), cassiterite, monazite, magnetite, ilmenite, limonite, titanates,

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* "*Yellow.* The colouring material of yellow rocks is almost always limonite. Yellow sandstones, beds of ochre, the weathered crusts of many limestones and of numerous ferruginous crystalline rocks furnish illustrations."—(Sir Archibald Geikie, "Outlines of Field Geology.")

niobates, corundum, zircons, cinnabar, sperrylite, garnets, spinels, precious stones, wolfram, scheelite, gadolinite, fergusonite, samarskite, atacamite, etc.

In examining sands for the precious metals a considerable quantity, say 20 lbs., should be carefully panned down, and any concentrate obtained should be very carefully examined. It must be borne in mind that gold is not infrequently coated with rust so that its characteristic yellow colour is not readily seen, and in this condition it does not readily amalgamate with mercury.

In addition, as a very small quantity of gold or platinum would under favourable conditions yield good returns, a very careful search is advisable. As gold, platinum, cassiterite, and monazite are all unaffected by either hydrochloric or nitric acid used *separately*, any concentrate may be cleaned by the aid of either of these acids.

If a concentrate is obtained which is supposed to contain gold or platinum, a fire assay should certainly be made. If either metal is found even in minute quantity a series of trial pits should be made so as to test the extent of the deposit as completely as possible.

Owing to the action of the wind and waves it often happens that surface concentrations of mineral are produced which can profitably be worked, whereas the whole body of sand could not be handled to pay. Care must therefore be exercised to see whether the layer of "pay dirt" is deep enough to justify further testing on a larger scale.

Gossan.—This term is given to the yellowish or brownish porous mixture of hydrated peroxide of iron, mixed with quartz or other rock which frequently forms the "cap" back or surface outcrop of lodes that have been weathered to such an extent that the action of air and water has oxidised and leached out most of the soluble constituents.

Thus a lode which carries iron or copper pyrites below may consist of gossan on the surface. This substance is therefore a valuable indication of a mineral-bearing lode, and may itself contain gold or silver which have resisted the action of the weather.

When gossan is found, particularly if it is porous (showing that a considerable amount of mineral was formerly associated with it), a trial pit should be sunk on the lode, and at the same time the gossan should itself be tested by fire assay.

Gossan has often been found to contain silver and gold, which has remained behind after the copper or lead that originally accompanied it has been leached out by the gradual action of water.

Many gossans contain tin in paying quantities, and therefore any gossan occurring in a tin district should be tested for that metal.

Bismuth Ochre (oxide) and *Bismuth Carbonate* are a pale yellow colour. When fairly pure, *i.e.*, not mixed with too much gangue, they can be readily recognised by reduction with carbonate of soda on charcoal before the blow-pipe. The metallic bead obtained is brittle. On re-heating a bismuth bead on a fresh piece of charcoal in the oxidising flame it will oxidise to a yellow mass and give a yellow incrustation.

Very small quantities of bismuth can be recognised by heating the suspected material previously mixed with a little sulphur and potassium iodide. A distinctive red incrustation of bismuth sulph-iodide is produced on charcoal in the blow-pipe flame.

Both the oxide and carbonate of bismuth are soluble in hydrochloric acid, and the solution obtained turns milky on dilution with water (owing to the precipitation of bismuth oxychloride) provided the amount of acid is not too greatly in excess. On the addition of sulphuretted hydrogen to the hydrochloric acid solution of bismuth a black precipitate of the sulphide is produced. Sometimes lumps of metallic bismuth, or sulphide of bismuth, are found imbedded in an earthy matrix containing the oxide or carbonate.

Certain *Iron Ochres*, containing a variable proportion of silica and impurities, are yellow. They are usually soft and earthy and the streak is rather lighter in colour than the specimen.

On ignition on charcoal the colour becomes a reddish-brown or brownish-black, and in the borax bead gives the reaction for iron. Boiled with hydrochloric acid, the oxide of iron is dissolved, yielding a yellowish solution, which yields the reactions for iron (*see also* under Limonite, and under Iron).

Tungstite, Wolframine, Tungstic Ochre.—The colour is yellow or yellowish-green.

It is usually structureless, earthy and soft.

Its specific gravity varies according to its degree of purity; the streak is a little paler than the specimen.

Before the blow-pipe it does not melt, but becomes darker, returning to its original colour on cooling.

It gives the characteristic reaction for tungsten in the microcosmic bead.

It is not soluble in acids, but dissolves in solution of ammonia or of caustic soda or potash, and if this solution is boiled with aqua-regia, the characteristic yellow tungstic acid will be precipitated.

This mineral is the result of the oxidation and decomposition of wolfram and might be found on the capping or outcrop of a wolfram lode.

Other minerals often accompany tungstic ochre, and should be looked for—copper, for instance.

Molybdite or *Molybdic Ochre.*—Is straw-yellow in colour; it may be earthy or crystalline. It is very soft and moderately heavy, about 4·5. On heating on charcoal a molybdic acid incrustation is formed (yellow when hot, white when cold) in the oxidising flame, which becomes blue on touching it for a moment with the reducing flame.

In a microcosmic bead it gives a yellowish-green in the oxidising and a green in the reducing flame. It is insoluble in acids, but dissolves on warming with ammonia.

It has not been found in quantity, but it might indicate the presence of a workable deposit of molybdenite.

Wulfenite, or Molybdate of Lead, is usually *yellow*, but may also be grey, brown, greenish, or reddish.

It is found in small crystals; soft and heavy. Heated on charcoal before the blow-pipe it decrepitates and melts readily; when carbonate of soda is added it yields a bead of metallic lead.

The mineral is decomposed by hot hydrochloric acid leaving a whitish-yellow residue of molybdic acid. This molybdic acid is soluble in ammonia, and if the solution is rendered faintly acid with nitric acid, the addition of phosphate of soda will give a canary-coloured precipitate.

Vanadinite (essentially vanadate and chloride of lead).—The colour is yellowish, sometimes tending to brownish-red.

It is usually soft. The specific gravity is about 7·0.

When heated before the blow-pipe on charcoal in the reducing flame it yields a button of lead. The lead may be expelled by roasting and a residue remains which gives in a microcosmic salt bead in the reducing flame a green colour, and a yellow colour in the oxidising flame.

A drop of nitric acid first produces a red colour, owing to the separation of vanadic acid, which then dissolves, giving a bright yellow.

Vanadinite is insoluble in hydrochloric acid, but is decomposed by aqua-regia. Vanadinite may be decomposed and the vanadic acid separated and estimated by fusion with potassium nitrate (*see* under "Vanadium").

Native Sulphur is usually yellow,* and is usually crystalline, the crystals being more or less transparent. Its specific gravity is about 2·0.

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* Owing to impurities it may be brownish or brownish-black.

In the closed tube it distils, and condenses in red drops (which become yellow when cold) on the upper portion of the tube. It takes fire readily when ignited in air, and burns with a blue flame, giving the characteristic smell of sulphurous acid gas; if pure no residue is left.

It is insoluble in hydrochloric acid and nitric acid, but is soluble in carbon disulphide.

Uranconite, Uranium Ochre, is yellow.

Zippeite is similar in composition to uranium ochre, but is crystalline. Both these minerals would probably be found associated with pitchblende.

Autunite is yellow, or green, and is described with torbernite under "Green Minerals" (*see* under "Uranium").

Iodargyrite and *Bromargyrite*, which are the iodide and bromide of silver respectively, are yellow or greenish. They give off purple and brown vapours respectively when heated on charcoal, and yield beads of metallic silver (*see* under "Silver").

These minerals are very rare, but are included on account of their high value.

Bauxite, essentially hydrous oxide of aluminium, usually with some oxide of iron.

It is usually yellow to yellowish-brown. The specific gravity is about 2·55. It is soft, and usually occurs in concreted granules.

Ignited before the blow-pipe on charcoal it does not melt.

Moistened with cobalt nitrate and re-ignited it turns a dull blue.

It is soluble in both sulphuric or hydrochloric acid (*see* under "Aluminium").

Orpiment, sulphide of arsenic.—The colour is yellow; the mineral is more or less transparent or translucent. The streak is the same colour. It is soft, the hardness being about 2. The specific gravity is about 3·5.

On ignition on charcoal it volatilises, and is decomposed, giving off white fumes of arsenious oxide, and sulphurous acid gas.

On ignition in the open air it is decomposed, yielding a white sublimate of arsenious oxide, and fumes of sulphurous acid.

Orpiment is not soluble in hydrochloric acid, but is decomposed by nitric acid or aqua-regia.

It contains about 60 per cent. of arsenic, and would therefore be a valuable source of arsenic if found in quantity.

Carnotite,* essentially a compound of uranium and potassium vanadates.—It occurs as a soft earthy material of a canary yellow colour, occurring in concretionary masses in sandstone, in Colorado. The specific gravity is variable.

It is soluble in hydrochloric acid on heating.

For the reactions and means of identification of vanadium and uranium, *see* under the monographs of those metals, it is used as a source of uranium and vanadium.

Topaz.—The colour is usually yellow, but the topaz may also be blue, pink, brown or colourless.

The hardness is 8·0; the specific gravity varies from 3·4 to 3·6.

Before the blow-pipe topaz does not melt, but a fragment moistened with cobalt nitrate and strongly heated yields the blue colour characteristic of aluminium compounds.

It is unaffected by acids.

It is often found embedded in quartz.

Topaz is found in Brazil, Pegu, Siberia, Saxony.

The finest topazes are found in Brazil and other parts of South America. This gem must not be confused with yellow quartz or yellow sapphire.

The Oriental Topaz or yellow sapphire is in all respects (except that of colour) identical with the sapphire.

It is found in Ceylon and Queensland.

Chrysoberyl.—A transparent yellow, brown or green mineral, found chiefly in Ceylon. Hardness, 8·5; specific gravity, 3·5—3·7; used in jewellery.

Beryl.—This mineral is of value as a precious stone. Different names are given to the various colours in which it occurs; the most important are the rich green variety known as emerald, and the blue and greenish called aquamarine. To be of value the colour should be pronounced and the material fairly free from flaws.

Beryls occur in hexagonal prisms as crystals which often appear cylindrical in form; the crystals are often in groups or aggregations. Hardness, 7·5; specific gravity, 2·75; chiefly derived from the Columbian Republic, Siberia, United States of America, Pegu, and Norway. Chemical composition: silica, 68·0; alumina, 18·3; glucina, 12·2; magnesia, 0·8; soda, 0·7.

Chrysolite.—This is a yellow variety of the olivine—it is used as a jewel.

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* But little is known of this rare mineral. I have, however, included it because a workable discovery would be of considerable value. It has been found and is being worked in Colorado.

Essonite.—A honey-coloured variety of garnet, sold by jewellers under the name of jacinth.

BLUE MINERALS.*

The following minerals are described or referred to under this section:—

Fluorspar (also found purple, white, and various shades of pink, red, green and yellow).
Calcanthite or Cyanose.
Chessylite or Azurite.
Vivianite.
Turquoise.
Lapis Lazuli.
Sapphire.
Amethyst.
Covellite.
Spinel (*see* under Red Minerals).
Topaz.
Aquamarine (*see* under "Green Minerals").

Turquoise.—The colour is blue or bluish-green.

The composition of the mineral is essentially phosphate of alumina with a small quantity of oxide of copper.

The lustre is waxy, and the specific gravity is from 2·6 to 2·8. The mineral is hard (about 6·0) and capable of a high polish.

Ignited before the blow-pipe on charcoal it turns brownish-black, but does not fuse.

It dissolves when powdered and warmed with hydrochloric acid, and the solution gives the reactions characteristic of copper, aluminium and phosphates.

Turquoise is found in Persia, Thibet, Egypt and New Mexico.

Lapis Lazuli.—The colour is light blue to deep blue.†

It is essentially a silicate of alumina with calcium, iron, etc. and often contains pyrites.

The lustre is vitreous, and specific gravity low; moderately hard.

Heated on charcoal before the blow-pipe it turns white, swells up and melts to an opaque whitish glass bead.

It is decomposed by hydrochloric acid, sulphuretted hydrogen being evolved, and a gelatinous deposit of silica is left.

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* "Blue is not a frequent colour in rock masses. It is often spoken of as the colour of many limestones, which, however, are grey or bluish-grey. Beautiful blots of pale blue and white occur among the schistose rocks, where the mineral kyanite abounds. Some clays and lithomarges are of a pale lavender hue. Patches of a bright small blue, or of an indigo tint, may be met with among peat-mosses, where some animal organism has decayed and given rise to the formation of phosphate of iron."—(Sir Archibald Geikie, "Outlines of Field Geology.")

† The colour is probably due to a compound of iron.

Fluorspar, calcium fluoride.—Is often a violet blue, but may also be purple, white, and various shades of pink, red, green, brown, and yellow.

It is transparent to translucent, with a quartz-like lustre. Its specific gravity is from 3·0 to 3·2, and its hardness about 4·0, so that it can be scratched by a penknife.

When heated it decrepitates, and on exposure to the dark after heating, many specimens glow with a phosphorescent light.

Strongly heated before the blow-pipe it melts to a bead, which is transparent while hot and opaque on cooling.

It is insoluble in hydrochloric and nitric acids, but is decomposed on heating with sulphuric acid, and the highly pungent gas that is evolved produces an etched or roughened surface on glass.

The crystalline form of fluorspar is characteristic. It crystallises in cubes or in octohedra. This affords one means of distinguishing it from the purple varieties of amethyst (a purple or violet variety of quartz), which crystallises in hexagonal prisms, terminated usually by a pyramid.

Fluorspar might be mistaken for some of the gem stones, but is distinguished by being soft enough to scratch with a knife. Large pieces of fluorspar are used for ornamental work, the mineral is also employed as a flux, being worth some £2 to £3 a ton. It frequently accompanies lead ore, and is also often found in tin veins.

Calcanthite, also known as Cyanose, Blue-stone, Native Copper Sulphate. The colour is blue or greenish-blue, the structure is crystalline. The lustre is vitreous and the streak colourless.

Heated in a closed tube it loses water and turns white. On further heating fumes of sulphuric acid are evolved, and the residue becomes brownish-red.

Before the blow-pipe, with carbonate of soda, a bead of metallic copper would be obtained.

Calcanthite is soluble in water, forming a light blue solution, which deposits copper on a clean knife blade, or when treated with ammonia becomes deep blue.

This mineral is a decomposition product of one of the sulphides of copper, and would only be found in countries where the rainfall is small. *In solution* in mine water; it occurs in several mines, and "cement copper" is prepared from such water.

The basic copper sulphate known as *Brochantite* is green.

Chessylite (Azurite), Blue Carbonate of Copper.—Deep azure blue, sometimes crystallized. The streak is somewhat paler

than the original colour. It is fairly soft, and has a specific gravity of about 3·5. In all the ordinary tests it gives the same reactions as malachite, and differs only slightly in the proportions of copper and water present. It is often more or less transparent.

Crysocolla is sometimes blue; it is described under "Green Minerals."

Vivianite, hydrous ferrous phosphate.—The colour is a dirty blue, or dull green, depending upon the direction in which it is viewed.

The mineral is *very soft*; specific gravity low, about 2·6.

Heated before the blow-pipe on charcoal it swells up, becomes white, and melts, forming a blackish bead, which is attracted by the magnet.

It dissolves in hydrochloric acid, forming a brownish solution, which gives reactions for iron and phosphates.

It does not occur in large quantity, and has no commercial value.

Covellite or *Covelline*, sulphide of copper.—Colour bright shining blue; it may occur massive, or in thin layers; soft, hardness about 2. The streak is greyish-black.

When heated on charcoal the sulphur burns off and a melted mass of copper sulphide is formed. After continued roasting, a bead of metallic copper is obtained.

It is soluble in nitric acid, sulphur separating, and a bluish-grey solution being formed.

It contains when pure over 60 per cent. of copper.

This ore should be tested for gold and silver.

Sapphire.—The sapphire is of the same composition and specific gravity and about the same hardness as the ruby, and is found under similar conditions.

It is of all shades of blue, yellow, green, and pink. Its colour, hardness, and specific gravity readily serve for its identification.

Sapphires are at present found in—Ceylon, Burma, Cashmere, Montana, Australia, and other places. They are usually found in the clay or gravel of an existing or ancient watercourse.

See "The Gem-Cutter's Craft," by Leopold Claremont, page 143.

Amethyst.—The amethyst is a purple colour, with vitreous or resinous lustre.

The hardness is 7·0 and the specific gravity 2·5 to 2·8.

Before the blow-pipe the amethyst is infusible. It fuses * if ignited with carbonate of soda.

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* The amethyst is nearly pure silica.

It is unaffected by acids, excepting hydrofluoric, in which it is very slowly soluble.

It is found in India, Spain, Siberia, and Auvergne, in France, the matrix being various igneous rocks.

The Oriental Amethyst, or, purple sapphire, is in all respects (except that of colour) identical with the sapphire.

It is found in Ceylon.

GREEN MINERALS.*

Many rocks have a greenish tint owing to the presence of small quantities of iron, others owe their greenish tint to traces of chromium.

The following minerals are described or referred to in this section:—

Garnierite (or Noumeite).
Melanterite.
Pyromorphite.
Glauconite.
Torbernite and Autunite.
Atacamite.
Malachite.
Zaratite.
Olivenite.
Apatite.
Chrysocolla.
Dioptase.
Brochantite.
Hiddenite.
Fluorspar.
Emerald.
Aquamarine.
Green Tourmaline.
Talc.
Chlorite.
Jade.
Jasper.
Apatite.
Sapphire.
Peridot.
Olivine.
Chrysoprase.
Some Garnet is green.
Some Jargoon is green.
Chrysoberyl.
Alexandrite.
Chalcedony.

Garnierite, also known as *Noumeite*,† is a silicate of magnesium and nickel.‡

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* "*Green*. Many red sandstones are marked with circular spots of green, due to the reduction of the iron oxide. Protosilicate of iron is the prevailing green pigment of rocks; carbonates of copper sometimes colour rocks of bright verdigris and emerald green tints. Many magnesian silicates are green, and impart green colours of various hues to the rocks of which they are constituents. Thus hornblende and augite give rise to dark bottle-green, and among the schistose rocks to paler apple-green and leek-green tints. The hydrous forms of these silicates, talc, chlorite, and serpentine form characteristically green rocks, the talc rocks shading off into white, and serpentine into black and dark red. Glauconite extensively diffused through certain sandstones gives them a characteristic green colour."—(Sir Archibald Geikie, "Outlines of Field Geology.")

† From Noumea, New Caledonia.

‡ The percentage of nickel is variable, and the mineral is often associated with copper silicate.

The colour usually varies from pale apple-green to an emerald-green, but it is also greyish. Structure, usually earthy, very soft and crumbly. Streak, whitish or light green. Very light, specific gravity about 2·6.

On ignition before the blow-pipe on charcoal, the light green colour changes to a brownish-black, and after prolonged exposure to the reducing flame a semi-metallic mass is left.

Chocolite is a variety of garnierite, but, as the name implies, is of a chocolate colour, due to an intermixture of iron oxide. By treatment with *dilute* hydrochloric acid, the iron may be dissolved, leaving the green mineral.

When treated with strong hydrochloric acid the above minerals are decomposed, yielding a greenish colour.

Pimelite is a name applied to a greenish-coloured clay containing variable amounts of nickel and magnesium silicates. The nickel would be rendered soluble on treatment with strong hydrochloric acid and heating.

Melanterite, Copperas, Green Vitriol, Native Ferrous Sulphate.[*] —The colour is light green, which becomes more or less rusty in the air. It is very soft and light. *The mineral is more or less soluble in water*, and has an inky taste.

On heating in the closed tube it first melts, loses water and becomes white, and then, after giving off fumes, red; strongly heated on charcoal, it leaves a brownish-black magnetic residue.

The solution in water gives a dark bluish-green flocculent precipitate on the addition of ammonia.

Pyromorphite consists essentially of phosphate and chloride of lead.—Colour, green, but often olive-yellow,[†] and occasionally brown; structure crystalline.

It is soft and brittle. The streak is white and the lustre resinous. It is very heavy, the specific gravity being 7·0.

Heated before the blow-pipe it melts[‡] very easily, and if the reducing flame is applied the blue-coloured flame characteristic of lead is obtained. With carbonate of soda on charcoal a button of lead is readily produced.

In the closed tube a white sublimate of chloride of lead is obtained.

It is not soluble in hydrochloric acid, but dissolves in nitric acid, and this solution yields reactions for phosphates.

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[*] This mineral is uncommon and of very little value.

[†] The yellow varieties often cootain a percentage of arsenic. The crystalline form of this mineral is very characteristic; it occurs in hexagonal prisms and affords, when the crystals are distinct, a means of distinction from several other somewhat similarly coloured minerals.

[‡] It fuses easily in a candle flame.

Glauconite or *Terre Verte* consists essentially of silicates of iron and Potassium.—The colour is a light or dull green, the structure earthy, moderately soft; specific gravity under 3·0.

Heated before the blow-pipe it fuses with difficulty to a blackish glass.

Heated moderately it is unaffected.

It is insoluble in water and acids. It is decomposed with fusion-mixture. It gives the reaction for iron in the borax bead. Impregnations of copper salts in sandstone which produce a similar colour are readily soluble in acids.

*Torbernite,** also known as Calcolite, copper uranium phosphate.—The colour is emerald-green. It usually occurs in flat crystalline plates, soft and brittle; specific gravity about 3·5.

Heated before the blow-pipe on charcoal the green flame coloration due to copper is obtained, and a black fused mass is left.

The borax bead gives the reactions for copper, and the reactions for uranium are obtainable with a bead of microcosmic salt, after the purification mentioned under "Uranium."

It is insoluble in hydrochloric acid, but dissolves in nitric acid, and gives reactions for copper and for phosphates. It has never been found in quantity, but it has a value as specimens.

Autunite, or calcium-uranium phosphate,* is usually earthy and structureless; it may be green or yellow.

Atacamite, copper oxychloride.—The colour is bright green or dark green, with vitreous lustre.

It is crystalline, moderately soft; the specific gravity is about 4·0. The streak is light green.

In the borax bead it yields the reactions for copper.

Heated before the blow-pipe on charcoal it colours the flame blue† with a green edge, and two sublimates are formed, a brown one of oxide of copper close to the assay and a white one of chloride of copper further off. Both are volatised on further heating. The assay piece becomes reddish-brown, and finally, after further heating in the reducing flame, yields a bead of metallic copper.

Atacamite is soluble in hydrochloric acid on heating, forming a green solution which deposits copper on a bright knife-blade. It is found in Chile, Peru, and West Africa.

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* Both these minerals are rare and seldom occur in workable quantities, but are inserted here on account of the high value of uranium. They would in all probability contain radium.

† Most copper compounds give a greenish flame, but copper chloride gives a blue coloration to flame.

*Malachite** (Green Carbonate of Copper).—This mineral usually occurs massive, sometimes soft and earthy, but often has, when broken, a silky lustre and fibrous structure, sometimes showing layers or rings of varying shades of emerald-green. It is often more or less transparent.

It is soft, and easily scratched by a knife-blade. The specific gravity is under 4·0.

Heated in the closed tube it turns black, giving off water.

Heated on charcoal the blow-pipe flame is tinged bright green, and a globule of copper is obtained.

The borax bead gives the reactions for copper.

The mineral effervesces and dissolves easily in cold dilute hydrochloric acid, giving a green solution which produces a copper stain on a steel knife-blade.

When pure, contains about 58 per cent. of copper. It is found in Russia, South America, and Australia.

Emerald Nickel (Zaratite), hydrated nickel carbonate.—Bright green in colour; more or less transparent. The streak is light green. Moderately soft. Specific gravity low, about 2·5.

Heated before the blow-pipe it turns black, and a residue of oxide of nickel remains, which is attracted by a magnet.

The mineral gives the reactions for nickel in the borax bead.

It is soluble in hot hydrochloric acid with evolution of carbonic acid gas, forming a green solution which, on the addition of ammonia, yields a blue solution.

Olivenite.—The colour is olive-green to brown, yellow, greyish. The streak is paler. The mineral is easily scratched with a penknife. Gravity about 4. It is a hydrated copper arsenate, and gives the usual copper and arsenic reactions before the blow-pipe.

Libethenite is a somewhat similar mineral, but usually of a brighter green colour.

Olivine is the name given by jewellers to a bright green variety of garnet, which is of considerable value. It is also the name of a mineral of which the gems peridot and chrysolite are varieties.

It is found in Egypt and in the Levant, frequently in basalt boulders. The hardness is about 6·5 to 7·0.

Apatite (calcium phosphate, with calcium chloride or Fluoride) is occasionally light green. It is described under "White Minerals," as it is more often white than green, but may be of several different colours.

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* Copper carbonate (and copper silicate) occur frequently as an incrusting or cementing material in rock, gravel, or sand in variable quantities. Boil in hydrochloric acid and test the solution for copper.

Chrysocolla, hydrous silicate of copper.—The colour is green, greenish-blue, or blue. It varies from translucent to opaque.

The specific gravity is slightly over 2·0. It is usually soft enough to be easily cut with a knife. The composition is very variable.

Before the blow-pipe it loses water and splits into fragments, and turns black, but does not melt. Like other copper compounds it colours the flame green, and is easily reduced to a metallic bead with carbonate of soda.

It is decomposed by hydrochloric acid, leaving silica in a pulverulent (*not* gelatinous) form. The solution will deposit a copper stain on a bright knife-blade. The mineral gives the usual copper reaction in the borax bead.

Dioptase is very similar to chrysocolla, but is said to differ from it in yielding gelatinous silica when treated with acid.

Talc, essentially magnesium silicate.—Many varieties are greenish-grey, soft, and occur chiefly in scales.

It may also be light grey, greenish-yellow, dark green or white. When it occurs in large transparent sheets it is of value for the same purposes as *mica*, namely, to form transparent fire-resisting chimneys or peep-holes in stoves, etc.

It has a pearly lustre, and is very soft, easily cut with a knife, and usually capable of being scratched by the finger-nail.

Heated before the blow-pipe it does not melt, but changes to a whitish colour and swells up.

Treated with hydrochloric or nitric acid it is not decomposed. It can be decomposed by fusion with alkaline carbonates.

Chlorite consists essentially of the silicates of aluminium and magnesium, with small quantities of iron.

It generally varies from light green to dark green or a dull bluish green, and is usually more or less translucent.

It turns white before the blow-pipe and melts at the edges. In the borax bead it gives the characteristic reaction for iron.

It is not affected by nitric or hydrochloric acids, but is decomposed by sulphuric acid.

It is generally soft and splits into thin laminæ.

The variety known as "peach" is sometimes hard and tough, and often forms part of the lode material accompanying cassiterite.

Demantoid.—This is a green variety of garnet used in jewellery; it is of considerable value. Hardness, 5·5; specific gravity, 3·84. Found in little nodules about the size of the finger nail; also occurs of a brown and yellowish colour. It is found in the Ural Mountains.

Jade, or *Nephrite* ("New Zealand Greenstone"), is an opaque, sage or apple-green mineral, used for ornamental purposes; it occurs in large boulders in New Zealand, China, and Afghanistan. The hardness is 6·5; the specific gravity is about 3·1.

Alexandrite.—A variety of chrysoberyl, green by daylight and red by artificial light; highly dichroic, and very valuable as a gem. The finest come from Siberia, and others from Ceylon.

Peridot.—A variety of the mineral olivine; it is transparent, and of a yellowish-green colour, and generally occurs in rhombic crystals, often worn and broken. Hardness, 6·5 to 7; specific gravity, 3·3; chemical composition: silica 39, magnesia 49·3, protoxide of iron 11·2, oxide of manganese 0·3, alumina 0·2. It is a well-known precious stone, and is found chiefly in Egypt, and in an inferior quality in the United States of North America.

The *Aquamarine* is sea green or pale blue; *see* under "Beryl."

The Emerald.[*]—The emerald is a bright green, with vitreous or resinous lustre.

Its hardness varies from 7·5 to 8·0, and its specific gravity from 2·63 to 2·75.

It is slightly rounded at the edges, when fine splinters are exposed to the full heat of the blow-pipe.

The emerald is found in India, South America and Siberia.

The matrix is frequently limestone, it is also found in talc and mica schists.

Stones of similar composition, but of different colour, are known as beryls or aquamarines, and are colourless, yellow or blue.

See "The Gem-Cutter's Craft," p. 176, by Leopold Claremont.

The Oriental Emerald, or green sapphire, is in all respects (except that of colour) identical with the sapphire.

It is found in Ceylon and Queensland, in the beds of existing or ancient water-courses.

Hiddenite is the name given to a rare form of spodumene, which is transparent, and occurs in bright green crystals. The hardness is about 6·0, and the specific gravity about 3·1.

Up to the present it has only been found in North Carolina, but it would probably have a value as a gem stone if found in

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[*] The composition of the emerald is anhydrous silicate of alumina and silicate of beryllium (glucinium). Fluorspar is often green, but as it is commonly blue or purple, it is described under "Blue Minerals."

sufficient quantity and in large enough pieces to allow of effective cutting.

THE MINERAL IS WHITE, GREYISH-WHITE*, OR COLOURLESS.

This section includes the following:—

- Calcite, marble, chalk, limestone, &c.
- Quartz and milky quartz.
- Felspar, including some with a flesh-pink tint.
- Barytes.
- Cerussite, including light-blue tints.
- Talc (some varieties).
- Meerschaum and Steatite.
- Magnesite.
- Kaolin.
- Gypsum.
- Aragonite.
- Anglesite.
- Albite.
- Celestine (some varieties are tinted a faint blue).
- Calamine.
- Electric Calamine.
- Cryolite.
- Calcium Phosphate.
- Apatite.
- Diamond.
- Zircon.
- Dolomite.
- Moonstone.
- Opal.

Colemanite }
Ulexite. } Boron minerals.
Boracite }

The mineral is white and soluble in water, or consists partly of a substance which dissolves in water and leaves a whitish residue on evaporation.

A list of the minerals soluble in water is given on a further page; they may be sodium, potassium, ammonium, aluminium, magnesium, copper, zinc or iron salts, or possibly boron compounds. They are not of sufficiently frequent occurrence to merit separate monographs, but, if their presence is suspected, they are all of them commercially valuable (unless in very small quantities), and can be readily identified by the tests previously given.

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* "*Grey* may be said to be the prevailing colour among rocks, especially of the older geological periods. In simple rocks like limestones it is often produced by the intermingling of minute particles of clay, sand, or iron oxide, or of amorphous carbonate of lime with the paler crystalline calcite of the comminuted organisms. Pure crystalline limestone is naturally snow white, as in Carrara marble. In compound rocks the prevailing grey hues depend on the mixture of a white mineral, usually a felspar, with one or more dark minerals like magnetite, hornblende, or augite, the lightness or darkness of the hue depending upon the relative proportions of the constituents. Should the felspar be coloured by iron, a pinkish hue may be given to the grey; or if the dark magnesian silicates have been altered into some of their hydrous representatives, the grey becomes more or less distinctly green. The old 'greenstones' owe their distinctive hue to this source."—(Sir Archibald Geikie, "Outlines of Field Geology.")

The Colour is Grey or White, Without Metallic Lustre.

Many silicates are grey without metallic lustre. Their specific gravity is usually from 2 to 3·5. They yield no sublimates, incrustations or metallic beads.

Some are decomposed by hydrochloric acid, others are unaffected.

The same observations which will be found under "Brown Minerals" apply equally here, namely, that such stones as yield no "head" in the pan, showing that there is no mineral of markedly higher specific gravity mixed with valueless gangue, and do not yield either metallic beads, incrustations, borax bead reactions, flame colorations, etc., and are not soluble in acids are probably silicates of no commercial value.

Apatite, impure calcium phosphate with fluoride or chloride of Calcium.—The colour is variable; next to white, perhaps the green varieties are most common, but it is also found yellow, red, violet-blue, brown, etc.

It is moderately hard; the specific gravity is about 3·2. The streak is white in all cases. The mineral is transparent to opaque, and has a resinous or vitreous lustre.

Apatite melts before the blow-pipe with difficulty, that is, thin fragments melt at the edge. After moistening with sulphuric acid and heating before the blow-pipe a bluish-green colour is imparted to the flame (presence of phosphorus).

Apatite dissolves without residue in nitric or hydrochloric acids; in sulphuric acid it also dissolves, leaving a white residue of calcium sulphate.

The solution in nitric acid gives the yellow precipitate with ammonium molybdate that is characteristic of phosphates.

For coprolites, osteolites, etc., *see* under "Phosphorus."

Ulexite, hydrated calcium borate, with sodium borate.—The colour is whitish, the mineral is opaque, and very soft.

The specific gravity is about 1·7.

It is slightly soluble in water. Heated on charcoal it melts if moistened with sulphuric acid, and heated before the blow-pipe the flame is coloured green. In the closed tube the mineral yields water.

Boracite, a compound of borate and chloride of magnesium, is similar in appearance, and tints the flame green when treated as above.

Heated with a cobalt salt it leaves a pinkish residue (presence of magnesia).

Scheelite, calcium tungstate.—The colour is usually white or pale grey, but is sometimes with slight yellowish or brownish or greenish tints.

It is moderately hard. It is heavy, the specific gravity being about 6·0. It may be crystalline or amorphous.

Before the blow-pipe, on charcoal, it is practically infusible and unaltered.

With borax it fuses to a bead which is transparent when hot, but white and enamel-like when cold.

With microcosmic salt it gives a bead with a blue colour in the reducing flame when cold, green when hot.

It is decomposed, when finely powdered, by prolonged boiling with nitro-hydrochloric acid, the lime dissolving, leaving the tungstic acid as a canary-coloured powder, together with any insoluble residue (silica, etc.) that may be present.

The yellowish tungstic acid is soluble in ammonia.

Tungstic acid yields a blue colour on boiling with dilute hydrochloric acid and a fragment of tin or zinc.

Scheelite may be found in alluvial or more frequently in lode-formation, usually with a gangue of quartz.

Cassiterite has occasionally been found light grey or nearly white in colour. It is very readily identified by reduction to the metal before the blow-pipe with cyanide of potassium.

When found in alluvial formations the white pebbles would immediately attract attention by their weight.

Steatite, Soapstone, Meerschaum, French Chalk, silicate of magnesia.*—There are several silicates of magnesia, which vary considerably in their physical characters. Steatite (soapstone, French chalk) is soft and sectile, generally white and opaque, with a specific gravity of about 2·5. It can be scratched by the finger-nail.

Meerschaum is similar to the above in composition and characters.

Talc is similar in composition, but is characterised by its transparency and by its occurrence in flat plates, which are flexible, and capable of being easily split into thin layers.

Ignited on charcoal, steatite becomes white and swells up, but is almost entirely infusible before the ordinary blow-pipe.

Treated with hydrochloric acid the silicates of magnesia are more or less easily decomposed.

Calamine, carbonate of zinc.—The colour is generally white, but it may be tinted yellow or brown by presence of impurities.

It has a vitreous lustre, is brittle and moderately hard.

The specific gravity is 4·5.

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* Serpentine is another form of magnesium silicate. It is of various colours; it is readily cut with a knife and carving tools, and as it is capable of taking a good polish is used for ornamental work.

On ignition the carbonic acid is expelled and zinc oxide remains.

On charcoal it gives the characteristic incrustation of zinc, which is yellow when hot, white when cold.

On moistening this incrustation with cobalt nitrate and reheating, the colour is changed to a dull green.

Calamine dissolves readily in hydrochloric acid with effervescence, leaving little or no residue.

Hemimorphite, or Electric Calamine (also known as Smithsonsite), is zinc silicate.—This mineral is similar to calamine, except that when treated with hydrochloric acid no carbonic acid gas is given off, and a gelatinous mass of silica is produced.

Cerussite, "White Lead Ore," carbonate of lead.—It is usually white or colourless, but is frequently tinted blue or green (by traces of copper), or it may be yellowish.

The streak is white. It is crystalline, or massive.

Moderately soft. It is heavy, the specific gravity being about 6·5.

Before the blow-pipe on charcoal it decrepitates, melts, and (under the action of the reducing flame) yields a button of lead together with the characteristic lead incrustation.

Cerussite is not at all readily soluble in hydrochloric acid,* but dissolves readily in dilute nitric acid, with evolution of carbonic acid gas.

The solution gives a bright yellow precipitate with potassium bichromate.

Magnesite,† carbonate of magnesium.—This mineral is similar in most respects to dolomite, but contains no calcium.

The colour is white when pure, and it may vary from transparent to opaque. The specific gravity is about 2·9. It is usually soft, but the hardness varies.

Heated before the blow-pipe on charcoal it glows, but is quite infusible. If heated with carbonate of soda no difference is produced, and the mass does not sink into the charcoal.

Magnesite heated on charcoal, and moistened with a cobalt salt and re-heated, becomes pinkish or pale reddish.

Magnesite after ignition turns moist red litmus paper blue. With hydrochloric acid the mineral dissolves readily with evolution of carbonic acid gas.

Dolomite, carbonate of calcium and magnesium.—The colour is usually white, but may be grey or tinged with various colours.

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* All other native carbonates are readily soluble in HCl.

† The term "magnesite" is sometimes applied to magnesium silicate, but it is preferable to restrict it to the carbonate.

The structure is generally crystalline, and the streak white or greyish.

It is brittle and only moderately hard; specific gravity about 2·9.

On ignition before the blow-pipe a whitish mass is left, which turns moistened red litmus paper blue.

The ignited mass, if moistened with cobalt nitrate and re-heated, is pinkish or pale reddish.

Soluble slowly in cold hydrochloric acid, more rapidly when the acid is hot, carbonic acid gas being evolved.

This solution gives the reaction for magnesium, *i.e.*, the crystalline precipitate of magnesium-ammonium phosphate (*see* under "Magnesium").

Marble, Limestone, Chalk, calcium carbonate.*—Marble is the ornamental variety of limestone. It is of various colours, and as it is readily cut without fracture and is either a pure white or of attractive colours and takes a fine polish, it is much used in building and ornamental work. Limestone is grey and fairly hard, chalk is white and soft.

All varieties of calcium carbonate become white and lose their carbonic acid on ignition before the blow-pipe, leaving lime which, when moistened with water, turns red litmus paper blue.

All varieties of calcium carbonate are readily soluble in hot or cold hydrochloric acid, with evolution of carbonic acid. The hydrochloric acid solution gives the characteristic brick-red colour to flame.

NOTE.—The red imparted to the flame by lime compounds appears greenish when viewed through a piece of cobalt blue glass; the flame coloration given by strontium compounds appearing violet or pinkish.

Felspar.—This is the general name given to a large group of minerals of specific gravity, usually about 2·5 to 2·75, and all hard, being next below quartz in the scale of hardness.† They are all essentially silicates of alumina with one or more of the alkali, or earthy metals, and although most often white or lightish, may be pale shades of most colours.

The felspars are not attacked by acids, but are decomposed by fusion by alkaline carbonates.

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[*] Aragonite, Calcite, Iceland spar, are all varieties of calcium carbonate. So also are pearl and coral, which, though of organic origin, consist of calcium carbonate with a little phosphate and silicate.

[†] Sometimes felspar is met with in a decomposing condition, in which case it may appear to the eye of the same appearance as is usual, but it is as soft as cheese.

Potash felspar has a commercial value when clean and pure. It is used in pottery making.

The chief are:—

- Orthoclase, containing potash.
- Albite, a soda felspar.
- Anorthoclase, a soda and potash felspar.
- Anorthite, containing lime.
- Oligoclase, Amazonite (a green variety).
- Sanidine, Andesite, and Labradorite, the latter being usually grey and showing a brilliant play of colours, chiefly blue tints by transverse light.

Moonstone, an orthoclase felspar which possesses a white or bluish-white blush; used in jewellery; found chiefly in Ceylon.

Labradorite.—A variety of felspar which exhibits flashes of brilliant colours.

Felspar enters into the composition of a great number of the common and rarer rocks, notably granite. China clay is the decomposition product of felspar in this rock (*see* under "Kaolin").

Kerargyrite,* Horn Silver, chloride of silver.—This mineral is usually white or pearl-grey, *on an absolutely fresh fracture*, which changes to brown or dull purple on exposure to light. It is often associated with native silver and with bromargyrite, iodargyrite, and embolite.

It is quite soft and sectile, and can be scratched with the finger-nail. The lustre is somewhat resinous to dull. The specific gravity is about 5·5.

Its melting point is so low that it fuses in the candle flame.

Heated on charcoal before the blow-pipe it yields a bead of silver.

If it is moistened with water, and rubbed on a clean piece of iron or copper a silvery stain is left.

It is not soluble in hydrochloric or in nitric acid, but is soluble in ammonia, and also (to a less degree) in a strong solution of common salt.

The name *Huantajayite* has been given to a double chloride of silver and sodium, which is of very rare occurrence.

Muscovite, Mica, potassium and aluminium silicate.—The light-coloured varieties are transparent or translucent. It is

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* This is one of those minerals, like cerussite and scheelite, which are of very great commercial importance, but which by reason of their possessing no metallic appearance are apt to be overlooked by prospectors. Kerargyrite would be easily recognised from the above description if it occurred massive, but if it were disseminated in fine particles through rock it would probably be missed unless a fusion assay were made.

somewhat harder than talc, and is distinguished by its flexibility and elasticity. The dark shining specks seen in ordinary granite are mica. The variety of commercial value is transparent and colourless, and capable of being split into thin flexible sheets.

Heated before the blow-pipe it turns white but will not melt, except perhaps slightly in very thin fragments. It will give the aluminium reaction after igniting strongly with a cobalt salt.

It is not attacked by acids.

Biotite is similar in many respects, but contains in addition magnesia and more iron. It is not decomposed by hydrochloric acid, but on boiling with sulphuric acid it is decomposed, leaving pulverulent silica in minute scales.

Colemanite, native calcium borate.—Colourless or white, usually more or less transparent.

It is moderately hard; the specific gravity is about 2·5.

Before the blow-pipe it decrepitates, swells up and melts partially. It communicates a greenish colour to the flame, which is best seen by mixing the powdered mineral with sulphuric acid and alcohol, and lighting the mixture in a dark place.

It dissolves in hot hydrochloric acid, and is decomposed. On cooling, boric acid separates out in needle-shaped crystals, which yield the green flame-coloration much more vividly than the mineral does.

The crystals are greasy to the touch, and when moistened with water turn yellow turmeric paper a brick red.

Anglesite,* Lead Vitriol, lead sulphate.—The colour is usually white, or colourless and transparent, but it is also found tinted yellowish, bluish, brownish, etc., by various impurities.

It is soft and heavy; specific gravity about 6·2. The streak is colourless; it may be crystalline or massive.

Before the blow-pipe on charcoal it decrepitates and melts, and in the reducing flame yields a bead of lead with the usual incrustation.

It is very slightly soluble in water; insoluble in hydrochloric acid, but dissolves when boiled with a solution of ammonium acetate, provided the mineral is in fine powder.

When brought into solution it gives the usual test for sulphates with a barium salt.

Kaolin, China Clay, hydrous silicate of alumina.—The colour is white. The clay is soft to the touch and has a soapy

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* This mineral is rare. It generally occurs with galena and is a product of the oxidation of that mineral.

feel, and to the naked eye appears structureless. Under the microscope it is seen to consist of small flakes or scales.

Heated before the blow-pipe it does not melt. After moistening with cobalt solution and re-heating it affords the blue colour characteristic of aluminium compounds.

It is unaffected by hydrochloric and nitric acids.

It is usually accompanied by particles of quartz and mica, but when separated from these by levigation it should be pure white, and on boiling with hydrochloric acid the liquid should not yield more than the minutest traces of iron.

(*See also* under "Aluminium.")

Alabaster, Gypsum, calcium sulphate.—The colour is usually white or colourless, and the lustre either vitreous or pearly.

It is very soft and sectile, and can be scratched with the finger-nail The specific gravity is about 2·2; the streak is white.

Heated on charcoal it swells up and becomes a white powder. In the closed tube it gives off water, and turns white and opaque.

It is soluble in hydrochloric acid, and gives the characteristic test for sulphates and fcr calcium, that is to say, the hydrochloric acid solution will give the characteristic brick-red colour in the flame test, and sulphates are indicated by the formation of a dense white precipitate on the addition of barium chloride to the hydrochloric acid solution of the mineral.

Gypsum is mined in England, America, and elsewhere, and is worth about 30s. a ton.

Selenite is a crystallized variety of gypsum, containing water of crystallisation; *Anhydrite* contains no water.

Barytes, Heavy Spar, barium sulphate.—It is white or colourless; if impure, may be tinged yellow, brown, pale red, etc.*

The streak is white. It is usually crystalline and often fibrous. The lustre is vitreous. It is not hard. The specific gravity, 4·5, is distinctly above that of ordinary rocks.

Heated before the blow-pipe it decrepitates, and the flame shows the characteristic pale greenish-yellow tint.

It fuses when ignited with carbonate of soda, and the melted mass sinks into the charcoal.

It is not soluble in acids, until it has been fused with carbonate of soda; the melted mass is then partially soluble in water, and the filtrate gives the reaction for sulphates; and the barium carbonate, which is insoluble in water, dissolves readily in hydrochloric acid.

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* When stained by iron compounds it is sometimes bleached by boiling in dilute sulphuric acid.

Witherite, barium carbonate.—It may be transparent, white, or greyish, or yellowish. It is crystalline or massive, with vitreous lustre. It is not very hard and the specific gravity is about 4·3.

Heated before the blow-pipe it does not melt, but the flame is tinged pale greenish-yellow, and the ignited substance is alkaline to red litmus paper.

It is dissolved by hydrochloric acid with evolution of carbonic acid gas. This solution gives a heavy white precipitate with a soluble sulphate.

Celestine, strontium sulphate.—The colour is usually white, but it may have a faint reddish or a faint bluish tint. It is more or less translucent. The structure is often fibrous or crystalline.

It is not hard, and its specific gravity, 4·0, is higher than that of most ordinary rocks, but less than the average for metallic ores.

It is brittle; the streak is white. It fuses to a white enamel-like bead before the blow-pipe, and the flame is tinged red.

It is only slightly soluble in acids, but may be decomposed on fusion with potassium carbonate, and is then converted into the carbonate and is then soluble in hydrochloric acid.

The aqueous solution affords the test for sulphates.

Strontianite, strontium carbonate.—The colour is white or pale grey, greyish-brown, green, &c.

The structure is usually fibrous. It is generally somewhat translucent with vitreous lustre. It is only moderately hard, and the specific gravity is about the same as that of celestine.

Heated before the blow-pipe it swells up, but is nearly infusible; the flame is tinged red.

It dissolves with evolution of carbonic acid gas in hydrochloric acid.

This solution gives a heavy white precipitate with sulphuric acid or a soluble sulphate.

Common Salt, Halite, sodium chloride.—Common salt or rock salt is white or transparent and colourless; when impure it may have a yellowish or reddish tinge.

It is soft and easily powdered. Before the blow-pipe it gives a bright yellow colour to the flame, decrepitates and melts.

It is readily soluble in water, and crystallises usually in cubes. With solution of silver nitrate it gives a white curdy precipitate of silver chloride.

The common impurities (in addition to earthy matters) are magnesium salts and calcium chloride. These are objectionable as they cause it to attract moisture and also affect the taste.

Quartz, Silica.—When pure, quartz is colourless or white, but it is often coloured by traces of metallic salts, sometimes grey and black. The lustre is vitreous, and the specific gravity is about 2·6. It is hard and cannot be scratched by a knife. It is often well crystallised, occurring usually in hexagonal pyramids or prisms terminated by pyramids.

Heated before the blow-pipe it is infusible, but dissolves in the borax bead, forming a clear colourless glass bead; in micro bead is undissolved, a skeleton of insoluble silica is left.

Heated with sodium carbonate on charcoal the carbonic acid is expelled from the carbonate of soda with effervescence and the resulting mass is soluble in water, and on the addition of an acid the silica is precipitated in a gelatinous condition.

Quartz is insoluble in all acids excepting hydrofluoric.

There are a great many varieties of silica, among which may be mentioned:—

Rock crystal, a specially pure variety.

Citrine, or false topaz, a yellow variety.

Amethyst, a purple crystallised variety, which, when pure, is used as a gem.

Smoky Quartz of a smoky brown colour; other varieties are rose quartz, milky quartz and black morion.

Flint and sandstone are impure varieties.

Jasper, *Chalcedony*, *Agate*, *Onyx* and *Carnelian* are more or less impure varieties, the three last mentioned being used in cheap jewellery.

Common Opal and *Precious Opal* are hydrated forms of silica; the latter, showing a play of colours, is used largely in jewellery.

Black Opal.—This variety of opal possesses all the characteristic coloured flashes of ordinary opal; the body of the stone is, however, black, or nearly so. Black opals have only been upon the market quite recently, and are considered rare.

Cryolite, the double fluoride of aluminium and sodium.—It is usually colourless or white; it may also be a reddish or a brownish tint, but is always more or less translucent.

It is soft and easily cut with a knife; the streak is colourless. The specific gravity is about 3·0. It is generally crystalline.

It is very fusible, melting in the flame of a candle.

If moistened with cobalt nitrate and ignited, the melted mass will be bluish, showing the presence of aluminium.

Cryolite is insoluble in hydrochloric and nitric acid, but dissolves on boiling in sulphuric acid, giving off intensely irritating vapours of hydrofluoric acid which will etch glass. (*See also* under "Fluorine.")

Calcium Phosphate.—Phosphatic rock may be white, but as it is more commonly brownish (owing to traces of iron) it is described under "Brown Minerals."

Zircon.—Zircon, the silicate of zirconium, is met with usually as a dull red or brownish sand, or in pebbles.[*]

While usually of a reddish tint it is sometimes found of a white-greyish, greenish or brownish colour.

The lustre is adamantine, and the specific gravity about 4·7.

Zircon does not melt before the blow-pipe, but glows brightly when strongly ignited.

The coloured kinds become greyish after ignition.

It is not affected by acids, but can be decomposed by fusion with either carbonate of soda or potassium bisulphate.

In either case it should be finely ground first and fused at a good heat. If the melt after fusion with carbonate of soda is dissolved in a slight excess of hydrochloric acid (so that the solution is faintly acid) the liquid will turn turmeric paper an orange colour. (*See* "The Gem-Cutter's Craft," by Leopold Claremont, page 191.)

Diamond.—Diamonds are usually colourless or nearly so, but may also be of various colours, or black.

Diamonds are found in beds or pipes of a characteristic quartzose conglomerate known as "blue earth" and also in river beds.

In such river beds there is usually a "wash" of characteristic pebbles in addition to the precious stones, and the appearances of this "wash" are recognisable by those accustomed to it.

In their natural state they appear as dull whitish pebbles usually more or less rounded.

The whitish coating that is often found on the diamond (and some other precious stones) may often be removed by soaking for some hours in spirit.

They are distinguished by their hardness, which is 10 (the highest in the scale), and by their specific gravity, which is 3·52. They may also be examined by the Rontgen rays, and are transparent to them, whereas glass and quartz, &c. are opaque.

The diamond cannot be scratched by anything except another diamond.

The specific gravity of the diamond is about 3·5.[†]

The diamond is quite unaffected by acids.

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[*] The zircons or jargoons found in Ceylon are sometimes cut and used in jewellery.

[†] For taking the specific gravity of gem-stones, *see* under "Physical Characters of Minerals."

Though hard, the diamond is brittle and therefore must not be tested by hammering it.

The dark brown or black diamonds, known as "carbons" or "bort," are employed in boring. These are found in Brazil; fragments of ilmenite have sometimes been mistaken for, or substituted for black diamonds.

Diamonds are found in South Africa, Brazil, India and Australia. (*See* "Precious Stones" by Dr. Max Bauer, page 113.)

MINERALS WITH METALLIC LUSTRE.

THE Mineral *has Metallic Lustre* varying from silver-white, lead-grey, and so on to iron-black, but with no tinge of yellow.

Platinum is steel-grey, usually somewhat dull externally.

The metal is usually found in small granules or scales, almost always in alluvial deposits.*

The streak is grey and shining. The most noticeable feature is its high specific gravity, which, when pure, is 21·0.†

Most specimens can be cut with a knife. Platinum is malleable, that is, it can be hammered out without breaking into fragments.

Before the ordinary blow-pipe it is quite unaltered, it melts before the oxy-hydrogen blow-pipe. The fact that platinum is unaffected by ordinary ignition and by boiling nitric acid, distinguishes it from all metallic sulphides. Heated on charcoal in contact with a fragment of lead, copper, or tin, the two metals combine and form an alloy.

Platinum is unaffected by fusion with borax or carbonate of soda.

Platinum is not affected by hydrochloric or nitric acid separately, but dissolves slowly in aqua-regia on boiling, yielding an orange-coloured solution, which gives a yellow crystalline precipitate with ammonium or potassium chloride.

Iridium is a metal of the platinum group. It is often found with platinum as an alloy or by itself.

Iridium is harder than platinum and cannot be cut with a knife. The specific gravity is about 22·5.

Heated in the open tube, no odour is given off (distinction from osmiridium).

It is insoluble in aqua-regia (distinction from platinum).

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* Iridium, Osmiridium, and Palladium are often found with or under the same conditions as platinum.

† Impure specimens may have a lower gravity. Some samples contain iron and may be attracted by the hand-magnet.

Osmiridium.—This native alloy of osmium and iridium is usually found in small shining metallic scales. The specific gravity is about 20·0. It is somewhat harder than platinum and cannot be cut with a knife.

Heated in the open tube the osmium is oxidised to osmic acid, which has a peculiarly unpleasant and characteristic odour. After strong and prolonged heating the osmium is to some extent volatilised.

Osmiridium is not attacked by aqua-regia, and does not alloy with lead (distinction from platinum).

For the uses of osmium and iridium *see* under the monograph on "Platinum."

Stephanite, Brittle Silver Ore, sulphide of silver with sulphide of antimony.—Iron-black, with metallic lustre. It is soft and brittle, the streak is also iron-black with metallic lustre.

Heated before the blow-pipe it melts and at the same time an incrustation of oxide of antimony is produced. The fused globule if ground with carbonate of soda and strongly heated in the reducing flame yields a bead of silver, together with a reddish incrustation of oxide of silver.

The mineral is not attacked by hydrochloric acid, but is decomposed by dilute nitric acid after heating.

The silver goes into solution, while sulphur and trioxide of antimony remain suspended in the liquid.

The presence of silver in the liquid may be detected rapidly by immersing a clean copper coin in it, or by evaporating the liquid and igniting the residue on charcoal, when a bead of silver will be produced.

Bismuth.[*]—Native bismuth is crystalline, soft, and brittle.

It is silver-white with a faint rosy tint, and bright metallic lustre. The streak is similar in appearance to the metal.

The specific gravity is remarkably high, being over 9·5.

Before the blow-pipe it melts easily[†] and oxidises with evolution of white fumes and with the formation of a yellow incrustation.

Bismuth is not readily soluble in hydrochloric acid, but dissolves easily in nitric acid; the solution on dilution with water becomes milky owing to the formation of an oxysalt.

A useful test for the recognition of bismuth even in small quantity with other minerals is the formation of a scarlet-red incrustation of bismuth sulph-iodide, when any bismuth com-

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[*] Bismuth ores often contain silver and sometimes gold, and should be examined for these metals.

[†] Native bismuth is very fusible and can be easily melted on a shovel at a moderate heat.

pound is well heated with twice its quantity of a mixture of sulphur and potassium iodide, on charcoal before the blowpipe.

Bismuthite, Bismuth Glance, sulphide of bismuth, is lead-grey with metallic lustre. Soft, with a streak similar to the mineral.

It is not readily attacked by hydrochloric acid, but is decomposed by nitric acid.

Molybdenite, molybdenum sulphide.—The colour is lead-grey, with brilliant metallic lustre. The mineral occurs in scales or soft flexible plates or flakes; easily scratched by the finger-nail, like graphite, it stains the fingers on handling. The streak (on porcelain or a white stone) is a grey with a dull greenish tint. On paper it makes a mark like a lead pencil.

Before the blow-pipe it does not melt, but gives off sulphurous acid, colours the flame yellowish-green, and becomes grey, giving an incrustation of molybdic acid, yellow while hot, white when cold. If the incrustation is touched momentarily with the tip of the reducing flame, the spot becomes blue.

Hydrochloric acid does not affect it, but it is changed to molybdic acid (greyish-white) when boiled for a long time with nitric acid; the action is slow; and the mineral must be in fine division.

It is easily distinguished from graphite, because the latter gives no incrustation, and evolves no smell of sulphurous acid on roasting; this test may be conveniently applied by roasting on a shovel, when molybdenite gives off a smell of burning sulphur, and the residue that remains is a greyish-white mass (yellow-white hot) without metallic lustre.

Pure molybdenite contains 60 per cent. of molybdenum.

Molybdenite may carry gold, and should therefore be tested for that metal.

Cobaltite, sulpharsenide of cobalt, often with varying amounts of Iron.—The colour is tin-white to lead-grey, with metallic lustre. It is hard, heavy, and crystalline, mostly in cubes. The streak is greyish-black.

Before the blow-pipe it gives off fumes of arsenious oxide and sulphurous acid gas, and fuses to a brittle bead, which is attracted by the magnet.

Heated in the closed tube it is hardly altered. In the open tube sulphurous acid gas and a sublimate of arsenious oxide are produced. Cobaltite does not dissolve in hydrochloric acid, but dissolves in nitric acid or in aqua-regia, giving a pink solution, with separation of sulphur.

Smaltite (cobalt arsenide), usually occurs together with Cloanthite (nickel arsenide).—It is tin-white to steel-grey with

metallic lustre. The streak is greyish-black. It is hard and heavy; specific gravity about 6·5.

Before the blow-pipe on charcoal arsenious oxide is given off, and a brittle bead is produced, which is attracted by the magnet. A small quantity of the mineral gives the characteristic blue colour of cobalt in the borax bead.

The mineral is not soluble in hydrochloric acid, but dissolves in aqua-regia, yielding a pinkish solution.

Native Silver.—The colour of specimens of silver is silver-white internally, but outside it is usually dull through oxidation.

It occurs in masses and also in tree-like and thread-like forms.

The streak is silvery, the hardness moderate; it can be cut with a knife,* that is, it is sectile and not brittle.

The specific gravity is about 10·5.

Heated before the blow-pipe it melts, yielding a silvery-coloured bead, which solidifies quickly, as silver has a high melting point. (There is often a faint brick-red incrustation of oxide of silver left on the charcoal.) The bead is malleable, and does not mark paper.

Silver dissolves readily in nitric acid; if any blackish residue is noticed it will probably be gold. Silver is often accompanied by horn-silver, the chloride, which is insoluble in nitric acid, but is easily reduced to the metallic state before the blow-pipe. The solution of nitrate of silver will deposit silver on a sheet of clean copper.

Galena, lead sulphide.—The mineral is lead-grey, with bright metallic lustre, on a fresh surface. After exposure to air and wet it becomes a dull-lead colour.

It is brittle and soft; the streak is the same colour as the mineral. The specific gravity is about 7·5.

It is always crystalline, and generally breaks readily into small cubical fragments.

Heated in a crucible or clay tobacco-pipe bowl with iron filings a button of lead is obtained.

Heated before the blow-pipe, sulphurous acid gas is given off and a yellow incrustation of lead oxide is formed. With the aid of the reducing flame a soft bead of metallic lead is easily obtained, which is malleable and marks paper. This distinguishes it from some dark varieties of zinc blende, which look rather like it. Zinc blende is soluble in hydrochloric acid, and forms no metallic bead before the blow-pipe.

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* Silver coins cannot be cut with a knife as they contain some copper added to render them hard.

The mineral is not soluble in hydrochloric acid, but is decomposed in nitric acid, a white turbid liquid being produced, which contains nitrate of lead in solution and sulphate of lead in suspension.

Pure galena contains about 86·5 per cent. of lead.

NOTE.—*All lead ores should be tested for silver*, as they all contain it, in varying amounts, frequently sufficient to make it worth extracting. This specially applies to galena, from which a very considerable amount of silver is extracted annually.

Argentite, Silver Glance, sulphide of silver.—The colour is a dark lead-grey, with little metallic lustre. The streak is shiny grey. The specific gravity is about 7·3.

It is soft and easily cut with a knife. On heating before the blow-pipe it melts and gives off sulphurous acid gas, and yields a bead of silver, which is bright, malleable, and does not mark paper.

The mineral is not soluble in hydrochloric acid, but dissolves in nitric acid. The solution gives a deep red precipitate, with a drop of potassium bichromate solution.

This ore is easily reduced to metal by fusion with potassium cyanide, and the button obtained should be tested (by solution in nitric acid) for gold; if gold is present it will remain undissolved as black mass or powder, which on being rubbed with a hard, smooth surface such as the end of a glass rod, or on being heated, will assume the familiar yellow colour of gold.

Marcasite, iron sulphide.—The colour is tin-white, with metallic lustre, on a freshly broken surface. It quickly decomposes in air and moisture, and the decomposed surface shows no metallic appearance.

In all respects, except that of colour, it is the same as iron pyrites, or mundic, which is described under "Yellow Minerals."

It is of very common occurrence, and is employed as a source of sulphur. ¶ It should be tested for copper, gold, and silver.

Jamesonite,* double sulphide of antimony and lead.—This mineral is similar in appearance to stibnite and to metallic antimony. The streak is black; it is very soft and very easily melted.

Ignited before the blow-pipe on charcoal the sulphur and antimony both oxidise and burn off and oxide of lead is left, which may be reduced to a bead of metallic lead.

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* Jamesonite is sometimes called "feather ore" on account of the feather-like appearance of its crystalline structure.

Jamesonite contains about 29 per cent. of antimony, whereas stibnite contains 71 per cent. There are a variety of rather rare compounds of antimony, *all of which are characterised by their softness and easy fusibility.*

All antimony ores should be tested for gold and silver.

Stibnite, also known as Antimonite, Antimony Glance, sulphide of antimony.—Stibnite is steel-grey or lead-grey, with metallic lustre. It is crystalline, soft and brittle. The streak is similar in colour to the mineral.

It is very readily fusible; a small fragment melts easily when held in a candle flame.

In the reducing flame of the blow-pipe it melts, giving off fumes of sulphurous acid gas and of oxide of antimony, and leaves a white incrustation and a brittle bead of metallic antimony.

It dissolves in hydrochloric acid with evolution of sulphuretted hydrogen.

When pure it contains 72 per cent. of metal, and is readily reduced to metal on heating with iron filings or turnings in a crucible with some carbonate of soda for flux.

Stibnite is employed by many tribes in Africa and elsewhere in the form of powder, as an application to the eyelids. Galena is also used for the same purpose.

Antimony.—This metal is found native in small quantities.

It is tin-white in colour, with metallic lustre, crystalline and exceedingly brittle. Moderately soft, specific gravity about 6·6. The streak is also tin-white and has metallic lustre.

Heated before the blow-pipe on charcoal it melts readily and evolves white fumes of oxide, with a white incrustation. The bead of metal is *brittle and does not mark paper.*

Metallic antimony is not soluble in hydrochloric acid, but on boiling with nitric acid is converted to a white oxide. The metal dissolves in aqua-regia.

A hydrochloric acid solution containing antimony deposits an *orange* coloured precipitate on passing sulphuretted hydrogen (together, of course, with the sulphur produced by the action of the nitric acid on the sulphuretted hydrogen).

All antimony ores should be tested for gold and silver.

Copper Glance, Redruthite, Grey Copper Ore, copper sulphide. —The colour is dark grey, with metallic lustre.

The specific gravity is about 5·8; it is crystalline, and moderately soft. The streak is greyish-black.

Heated before the blow-pipe it melts, fumes of sulphurous acid gas being given off. The blow-pipe flame is tinged greenish-blue, and a bead of copper can be obtained by vigorous application of the reducing flame.

In the closed tube a sublimate of sulphur is obtained.

The borax bead affords a green colour in the oxidising flame, and an opaque red bead in the reducing flame.

The mineral is insoluble in hydrochloric acid, but decomposed by nitric acid, a greenish-blue solution being produced, together with floating globules of sulphur, this solution turns blue with ammonia.

When pure this mineral contains about 80 per cent. of copper.

Fahl Ore, Fahlerz, Tetrahedrite, a sulphide of copper and antimony.*—The colour varies from grey to nearly black, with variable metallic lustre.

The specific gravity is about 4·8, the structure is usually crystalline in tetrahedrons. It is brittle and not very hard. The streak is similar to the colour.

Before the blow-pipe with carbonate of soda it yields a bead of metallic copper.

In the open tubes any sulphur, arsenic or mercury that may be present will be volatilised.

Fahl ore is not readily acted on by hydrochloric acid, but is decomposed by nitric acid, yielding a greenish-blue solution.

Stannite,† Tin Sulphide, or Tin Pyrites.—This ore is essentially sulphide of tin with (generally) varying quantities of iron and copper sulphides and occasionally arsenic.

The colour may be steel-grey, greenish-grey, bronze-coloured; in all cases there is more or less metallic lustre. It is sometimes crystalline.

The hardness is moderate, the specific gravity is about 4·5.

The streak is blackish.

Before the blow-pipe it melts to a brittle bead containing tin, copper, and iron sulphides, some sulphur being burnt off.

Ignited on charcoal with soda, a metallic bead is obtained, consisting of tin (and copper if present), which may be white or yellowish.

It is not decomposed by hydrochloric acid, but nitric acid decomposes it with violence; the sulphur floats on the liquid in yellow globules and the solution is green and turbid. On diluting with water the tin is seen as white metastannic acid, while the copper remains in solution and shows the characteristic green colour.

Mispickel, Arsenical Pyrites, Arsenical Mundic, sulphide of arsenic and iron.—The colour is tin-white to a dull lead-grey, with metallic lustre. The specific gravity is about 6·0; the

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* This ore, or rather group of ores, consisting essentially of the sulphide of copper and antimony, frequently contains arsenic, silver, &c., in varying quantities.

† This ore is rare, but would be of considerable importance if found in quantity.

streak is blackish grey. After exposure to air and rain it sometimes becomes nearly black on the outside.

It is brittle, crystalline and hard, the hardness varies a good deal according to the locality.

On heating in the closed tube, a sublimate of sulphur is obtained.

On being struck smartly by a hammer it gives a characteristic smell of garlic.

Heated in the open tube, sulphurous acid gas and fumes of white arsenic are given off. Part of the arsenical fumes will condense, forming a white incrustation. This incrustation can be entirely volatilised on further heating.

Before the blow-pipe on charcoal mispickel glows and partly volatilises, giving white fumes, having the odour of garlic and fumes of sulphurous acid gas, while a brownish mass of iron oxide is left.

The mineral is not soluble in hydrochloric acid, but is decomposed by nitric acid, with liberation of flakes of sulphur.

Pure mispickel contains about 46 per cent. of arsenic, but the ore as mined generally contains from 10–20 per cent. of arsenic expressed as As_2O_3; it is not customary to stamp or dress it (other than by hand-picking) but to calcine it, when the white arsenic is condensed in flues.

Native Amalgam, silver and mercury.—This compound is silver-white in colour, and the streak is silver-coloured. It is not hard, and may be malleable or brittle according to the percentage of silver, which may be from 25 to 85 per cent. Specific gravity varies from 10 to 14.

Heated before the blow-pipe the mercury would be expelled and the silver would melt to a bead.

It is insoluble in hydrochloric acid, but readily soluble in nitric acid with evolution of red fumes and formation of the nitrates of the metals.

The Tellurides.—There is a group of minerals containing tellurium, several of which are very valuable on account of the gold and silver that they contain.

Their general characters are as follows;—

1. They all possess metallic lustre.
2. They are very soft and leave a greyish mark on paper.
3. They are all heavy.
4. They all melt very easily or give off whitish fumes when heated in air.
5. When heated in the open tube they give a white sublimate, which condenses near the heated part of the tube, and on further heating this white sublimate fuses into colourless drops.

The following tellurides are regarded as distinct varieties:—

*Calaverite, tellurium, gold and silver.
Sylvanite, tellurium, gold and silver.
Petzite, tellurium, gold and silver.
Nagyagite, tellurium, gold, lead, etc.
Hessite, tellurium and silver.
Coloradorite, tellurium and mercury.
Krennerite, tellurium, gold and silver.

For further tests for tellurium *see* under the monograph on Tellurium.

Wolfram always has a semi-metallic lustre of varying brilliancy on a freshly broken surface, some samples being a steel-grey, others a nearly iron-black. As this colour is most common, the mineral has been described under "Black Minerals."

Graphite sometimes has a semi-metallic lustre, but is also described under "Black Minerals."

THE MINERAL HAS A DISTINCT METALLIC LUSTRE WITH A TINGE OF YELLOW.

THE following are included in this group:—

Gold.
Iron pyrites.
Millerite.
Chalcopyrite.
Bronzite.
Yellow Mica.
Pyrrhotite.

Gold is pale yellow or bright yellow, with very high metallic lustre. It may occur in specks, flakes, nuggets and (very rarely) in crystals. Very heavy, having a specific gravity over 19·0.

It is soft and sectile, and can be pricked with a needle and cut with a knife without breaking into fragments. Under the hammer it flattens. These characters distinguish it from iron and copper pyrites, yellow mica, etc., which somewhat resemble it in colour and lustre. A common test is to wet the stone showing yellow metal and look at it in the sun, then shade it from the sun and look again, and if it is gold it retains the same lustre.

Streak, golden. Before the blow-pipe it melts to a bright golden bead. It is insoluble in hydrochloric acid and nitric

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* Calaverite is described as having a yellow metallic lustre by some writers. The other tellurides have a silver-white or steel- or iron-grey lustre.

acid applied separately, but dissolves in aqua-regia on boiling, forming a bright yellow solution.

A few drops of this solution added to a few drops of solution of protochloride of tin, produce a purple colour. Before treating a sample with aqua-regia, to test it for gold, it is well to thoroughly roast the sample free from sulphur, arsenic, etc., and to remove anything soluble in hydrochloric acid.

It forms an amalgam with mercury and is recovered by distilling off the mercury.

It alloys with lead and is recovered by cupellation.

Gold occurs in three forms: (1) In particles in rock or sand, which may be visible before crushing or are so after crushing and panning; (2) enclosed in sulphides or oxides; (3) in combination as telluride of gold.

Native gold always contains a proportion of silver varying from 1 per cent. to 15 per cent. and occasionally more, the average being usually under 10 per cent.

Millerite, sulphide of nickel.—A comparatively rare mineral, is yellow with metallic lustre. It occurs usually in needle-shaped crystals. It is brittle, but not hard. Before the blow-pipe on charcoal sulphurous acid is given off. The ignited mass dissolves in hot hydrochloric acid, giving a green solution, which yields the reactions for nickel.

The mineral itself is insoluble in hydrochloric acid, but dissolves in aqua-regia.

Pyrites, also known as *Mundic*, Iron Pyrites, sulphide of iron.—Colour, brass-yellow to light yellow with strong metallic lustre. Occurs massive or crystallised, usually in cubes. Moderately heavy, specific gravity about 5·0. It is brittle, but *hard*. The streak is brownish- or greyish-black. Heated before the blowpipe fumes of sulphurous acid are given off and the mineral melts to a black bead which is attracted by the magnet.

Heated in the closed tube a sublimate of sulphur is produced.

Pyrites is insoluble in hydrochloric acid, but is decomposed with violent ebullition in nitric acid, forming a reddish-brown solution.

Pyrites contains more than half its weight of sulphur and is used as a source of sulphur and in the manufacture of sulphuric acid. Pyrites frequently contains copper, gold, and silver, and should always be tested for these metals. To test for copper, decompose the ore with nitric acid, and then add excess of ammonia, when a bright blue solution will appear (when the reddish precipitate of iron has settled) if copper is present.

Marcasite is an iron pyrites of the same composition, but nearly tin-white in colour and crystallising in the rhombic system.

When pure, pyrites contains 53·4 per cent. of sulphur.

Chalcopyrite, Copper Pyrites, sulphide of copper and iron.—Colour, yellow, sometimes iridescent purple when the surface has become oxidised with strong metallic lustre. It is the principal ore of copper.

Moderately heavy, the specific gravity being about 4·0. It is brittle and considerably softer* than iron pyrites, which is similar in appearance. It is crystalline, usually hexagonal. The streak is greenish-black. Before the blow-pipe it gives off sulphurous acid gas and melts to a bead consisting of copper and iron sulphide.

Heated in the closed tube it decrepitates, turns black, and gives a sublimate of sulphur. With the borax bead gives indications of copper and iron.

It is insoluble in hydrochloric acid, but is decomposed with violent ebullition in nitric acid, forming a greenish-blue solution which deposits copper on a knife-blade.

When pure it contains about 34 per cent. of copper.

Chalcopyrite is not necessarily associated with iron pyrites, but almost all chalcopyrite is a variable mixture, containing less copper and more iron sulphide than the theoretical composition would indicate. Much of the "yellow copper ore" as sold to the smelters contains no more than 7 or 8 per cent. of copper.

Bronzite is a variety of enstatite containing iron; it is essentially a silicate of magnesium and iron.

It is usually bronze-coloured with semi-metallic lustre, but may also be greyish-green and brown. Like most of the common silicates its reactions are mostly negative ones.

It is hard but brittle, and of rather high specific gravity, about 3·0.

Before the blow-pipe it is infusible, or only shows signs of fusion on the edges of thin fragments.

It is not affected by hydrochloric acid; in the borax bead it yields the reaction for iron.

It is of no commercial value and is only inserted here because its appearance is sometimes somewhat metallic.

Native Copper is pale red in colour when a fresh unoxidised surface is exposed, by fracture or filing. After exposure to the air it becomes tarnished, and the mineral is therefore described under "Red Minerals."

If it has been exposed to the wet it is often stained with bluish or green incrustations of oxides or carbonates.

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* Chalcopyrite can be scraped away with a knife, whereas iron pyrites is too hard to cut.

Pyrrhotite is a magnetic iron pyrites, usually darker in colour than ordinary iron pyrites.

LIST OF MINERALS SOLUBLE IN WATER AND CERTAIN ACIDS.

While a great deal of valuable information is obtainable by the application of the blow-pipe reactions enumerated above, all minerals should also be examined as to their behaviour with water, hydrochloric and nitric acids, separately and together, and cases where no reaction takes place, with sulphuric acid, and by wet tests after treatment of the mineral by fusion.

The results of such tests are given in the monograph on each mineral in all cases where any characteristic reaction takes place, and in addition many of the ores have been classified here according as they are soluble in water or acted on by the various acids.

1. *Minerals Soluble in Water.*—The following table includes all the mineral salts that are found native. They are naturally only likely to be found in countries where the rainfall is not very great, or in deposits at some depth in the ground where they are protected from the action of water, or as an efflorescence on the surface of the ground, or crystallising out from the waters of lakes. Sometimes they occur in solution, as for example the copper-bearing water that is utilised at some mines for the production of "cement copper," or the springs containing lithia in solution which have been found in different parts of the world, or the steam jets containing boric acid found in certain volcanic regions.

If the soluble salts are found mixed with earth a weighed quantity should be taken and boiled with water and the liquid filtered through flannel or some other suitable fabric and evaporated to dryness and weighed.

There are only three *coloured* soluble salts likely to be found native.

Sulphate of copper or calcanthite (blue), which results from the oxidation of copper sulphide.

Sulphate of iron, or melanterite (pale green), resulting from the oxidation of pyrites, and carnallite, which is essentially potassium chloride, coloured red or pink by iron oxides.

The white minerals soluble in water which are found native are more numerous and comprise the following:—

Sodium chloride (Halite).
Sodium carbonate (Trona).
Sodium sulphate (Mirabilite).
Sodium nitrate (Chili Saltpetre).
Sodium borate.

Potassium nitrate (Saltpetre).
Potassium chloride (Carnallite).
Aluminium sulphate.
Magnesium chloride.
Borax.
Boric acid.

It is not impossible that deposits of ammonia salts might be discovered in addition to guano, but deposits of ammonia salts do not appear to have yet been discovered in workable quantities.

It is unnecessary to repeat the tests for the recognition of these minerals as all the tests will be found under the monographs of their respective metals.

2. *Minerals Soluble in, or Decomposed by, Hydrochloric Acid.*—(Some dissolve easily, some require long boiling[*]):—

Calcium carbonate in all forms—namely, limestone, chalk, calcite and marble.

Some compounds of iron (chalybite, limonite, and hæmatite) siderite easily (ilmenite and magnetite only under pressure).

Dolomite and magnesite.
Crocoisite and wulfenite.
Emerald nickel.
Calcium phosphate.
Wagnerite (magnesium phosphate).
Pyrolusite, diallogite.
All the oxidised ores of copper.
Ulexite (hydrous borate of lime and soda).
Zincite, blende and calamine, colemanite and zinc silicate.
Witherite and strontianite.
Stibnite, erythrine.
Asbolan (oxide of manganese and cobalt).
Vanadinite.
Bismuthite.
Greenockite (cadmium sulphide).
Uranite.
Wolfram.
Scheelite.

Gossan and ferruginous sandstones and many rocks tinted with iron will, when treated with hydrochloric acid, part with their iron or a portion of it, leaving the sand or insoluble portions unaffected.

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[*] In testing whether a mineral is soluble in hydrochloric acid it should first be finely powdered, about 1 gram should be treated with about 5 c.c. of acid. If there is no apparent action in the cold, it should be boiled for half an hour, adding more acid if necessary. In order to see if any has gone into solution evaporate a few drops in a porcelain dish.

A good many compounds containing silica are decomposed, for example, hemimorphite, lepidomelane, willemite, and troostite are decomposed, leaving gelatinous silica, while chrysocolla, labradorite, meerschaum, serpentine, sphene, wollastonite, and some other silicates yield non-gelatinous silica. The silica from silicates after decomposition by fusion and treatment with hydrochloric acid is always gelatinous until it has been exposed to a certain degree of heat.

3. *The Mineral is Insoluble in Water and in Hydrochloric Acid, but is Decomposed by Aqua-regia.*—Galena, iron pyrites, copper pyrites, cinnabar, arsenical pyrites, silver glance, nickel pyrites, stannine, pitchblende, argentite, bismuthine, molybdenite (fine) slowly, platinum, native silver, gold, mercury, the tellurides, etc.

4. *The Mineral is Insoluble in Water and the above Acids.*—Quartz, granite, mica, rutile, cerargyrite, barite, celestite, slate, clays, horn-silver, cassiterite, chromite, orthoclase, quartz-sand and sandstone, asbestos, monazite, osmiridium. Columbite, tantalite, spinel, corundum, and almost all gem-stones.

Many compounds of silica are unaffected,* and practically all the gem-stones.

A few minerals are conveniently opened up or decomposed by sulphuric acid, such as clays, fluorspar, cryolite.

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* *See* under "Brown Minerals," "Grey Minerals," and under "Silica."

MONOGRAPHS ON THE METALLIC AND NON-METALLIC ELEMENTS.

Their compounds, and the uses to which they are put, their market value, fluctuations in price, the amount raised and used annually, the condition or degree of purity to which they should be dressed for sale.

In addition to giving information to assist the reader to recognise the various minerals, the author has considered it advisable to include a short account of the compounds and uses of each separate element, and in some cases the approximate market value of certain ores when they have been dressed up to the quality required for sale. In some cases it has been possible to include the approximate quantity of the various minerals which are raised and used annually. This information can only be given in a few cases, but it is hoped to extend it in future editions.*

In the case of the rarer metals, and of those which, while not actually rare, have at present only few applications, prices have not been given, as they fluctuate so much, but the author will always be glad to reply to queries by post.

ALUMINIUM.

Aluminium.—Aluminium is one of the most abundant constituents of the earth's crust, next to silicon. It enters into the composition of the majority of the rocks.

Aluminium is not found native. It used to be produced by the action of metallic sodium on cryolite, but is now made by the electrolysis of aluminium chloride. It cannot be prepared by any ordinary method of smelting on account of its powerful affinity for oxygen.

On account of its lightness and capability of taking a good polish it is employed to some extent in the manufacture of spoons, forks, water-bottles, cooking utensils,† etc. With zinc it forms an alloy which is coming into extensive use in motor-car construction.

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* The author is well aware of the scantiness and incompleteness of the information included on many of these important points; it has, however, seemed to be so important to a prospector to know what kind of demand there is, and what sort of price he may expect to get for any mineral he may find, that as much information as possible has been included, and it is hoped to increase this in later editions. The prospector must remember that the finding of an ore or mineral even in a large quantity does not complete his work. He has still to ascertain whether it has a commercial value as it is, or whether it can be dressed up to a marketable standard.

† Soda attacks it, and so do vinegar and acid fruits.

Aluminium forms only one oxide, Al_2O_3. The sapphire, ruby, emerald, and amethyst have already been described under their respective colours.

Corundum is a less pure form of alumina. Its colour is most often a brownish-black.

It is very hard, and is used as an abrasive. The granular form of corundum is known as emery.

None of these forms of native alumina are affected by acids, but they may be decomposed by fusion with potassium bisulphate.

Corundum and the precious stones above mentioned are all distinguished by their remarkable hardness.

They easily scratch quartz. They are infusible before the blow-pipe, and their specific gravity is noticeable, being about 4·0.

Bauxite is a variable mixture of oxide of aluminium and oxide of iron; it varies in colour from pale yellow to dull red, but is most frequently of a brownish tint. The specific gravity is about 2·5, when pure it is white or greyish, and contains nearly 74 per cent. of alumina, but ordinary varieties contain varying amounts of iron and silica.

Aluminium silicate is the basis of all clays.

Ordinary clays consist of aluminium silicate with mechanically mixed impurities, and usually a certain amount of iron oxide.

Fuller's earth has been described under "Brown Minerals"; it is found in the neighbourhood of Bedford, and is worth about £1 8s. 0d. a short ton (2,000 lbs.).

Cryolite is a double fluoride of sodium and aluminium. It is usually colourless or white, but is also found tinted various colours and nearly black.

It was formerly much in demand for the preparation of aluminium, and is still used for this purpose.

Kaolin, or china clay (hydrous silicate of alumina), has already been described under "White Minerals."

It is employed in the manufacture of high-class pottery ware. Large quantities are obtained annually from Cornwall.

It results from the decomposition of felspar and granite, and is usually accompanied by more or less quartz and mica.

It is worked by bringing in a stream of water to wash down the side of the deposit in such a manner that the fine particles of clay are carried forward in suspension in the water.

The heavier portions, such as quartz and mica, which it is desired to remove are caught in settling pits and the clay itself is caught in settling pits arranged so that the stream flows so slowly that the clay has time to deposit. As these pits fill

they are dug out, and the clay is dried on heated flues. In the preparation of the better qualities it is very essential that no trace of iron should get into the finished product, as if so a perfectly white porcelain could not be made from it. The price of china clay prepared for the market varies from 15s. to over 60s. per ton.

The value of a deposit of china clay would depend very much on local conditions, but a large deposit of good quality, if water were available, and there were facilities for shipping the finished product, would be deserving of careful attention.

China stone is a mixture of felspar and quartz, and is quarried and shipped off to the potteries either in lump or after being ground; it is used for making the finer sorts of porcelain.

Alunite may be in crystals, fibrous or granular. Specific gravity, 2·5—2·7; hardness, 3·5—4·0. It is usually translucent. Colour, white to grey, pink or red. Composition when pure=

$$K_2O=11,\ Al_2O_3=37,\ SO_3=38,\ H_2O=13.$$

It is not soluble in water, but after roasting and lixiviating, alum can be prepared from it.

Corundum.—Colour, common varieties, reddish, colourless, grey, or greenish. It is extremely hard, being second only to the diamond in this respect. The gravity is about 4. Its composition is nearly pure alumina. Emery is a dark variety of corundum. Heated strongly on charcoal with a drop of solution of cobalt nitrate it gives a blue colour. It fuses with borax to a clear glass. The *Ruby* is a pure red variety of corundum. It is also occasionally a fine blue colour and is then termed sapphire, the colour being the only difference between it and ruby. It crystallises in hexagonal pyramids.

Spinel (Balas Ruby).—Usually rose-red or violet, sometimes brown, black, or even blue or green. Hardness rather less than true ruby. Gravity about 3·5. Composed of alumina and magnesia, but may contain iron, silica or lime. It resembles garnet, but is infusible alone. It is used largely in jewellery. It crystallises usually in octahedrons.

Garnet.—This is a name applied to a large number of minerals, all crystallising in the cubic system, usually in the form of rhombic dodecahedrons. They contain essentially silica, also commonly alumina, magnesia, lime, or iron, and sometimes manganese or chromium. The hardness is about that of quartz or a little harder, and the gravity ranges from 3 to 4. The streak is always white or whitish. Before the blow-pipe most of the garnets will fuse to a dark glass. The colour is

usually a variety of red, ranging from pink to deep crimson, but often brown, purple, and sometimes green. Specimens with good colour and free from flaws are used to a certain extent in jewellery. Garnet that is useless in jewellery has a limited use as an abrasive.

ANTIMONY.

Antimony.—Native antimony has been already described as well as the principal ore, stibnite.

The chief application of antimony is to harden lead for the preparation of type-metal for printing and for the preparation of bearing metals ("Babbitt," etc.). When 75 per cent. lead is mixed with 25 per cent. of antimony the resulting alloy is tough, and instead of contracting on cooling, it expands slightly when solidifying, and hence takes all the fine lines of a mould.

The metal is prepared from the sulphide by reduction with metallic iron. If there are earthy impurities in the ore it is treated by heating in a crucible with a false bottom, fitted inside a larger one, which is kept covered to exclude air.

The sulphide melts very easily, and runs through the false bottom into the outer crucible; it is then remelted with a proper proportion of iron, and the crude metal refined.

The sulphide is used in the manufacture of fireworks, india-rubber, and linoleum making.

It is also employed to a small extent in medicine. Antimony ores should be tested for gold and silver, as they are sometimes present.

Jamesonite is a double sulphide of lead and antimony.

Valentinite and *Senarmontite* are oxides of antimony.

Kermesite is an oxysulphide.

Cervantite, the oxide of antimony, also known as antimony ochre, is yellowish in colour and moderately hard; the streak is lighter in colour.

On ignition on charcoal with carbonate of soda a bead of metallic antimony is produced.

Cervantite is soluble in hydrochloric acid on warming.

None of these minerals are of much commercial importance, as they have not been found in large quantities.

The applications of antimony are somewhat limited, but the supply is at present small, and it is deserving of attention.

The present price of metallic antimony is about £33 per ton. It reached £95 a ton during a part of the year 1907.

The world's production of antimony is about 10,000 tons. It is produced chiefly in Japan.

There are several promising deposits in Cornwall.

ARSENIC.

Arsenic.—This metal is found native, but it is chiefly obtained from mispickel, a sulphide of iron and arsenic; it is also obtained as a by-product from the arsenical sublimate yielded by roasting tin-ores, mixed with arsenical compounds.

Mispickel has already been described under "Minerals having Metallic Lustre."

Mispickel (also known as arsenopyrite) contains about 45 per cent. of arsenic. It is sufficiently hard to strike fire with steel. When roasted, with free access of air, the sulphur is converted into sulphurous acid and the arsenic into "white arsenic," the iron being converted to oxide. The calcining of mispickel is carried out in furnaces of different designs. When in lumps it is burnt in bottle-shaped furnaces by its own heat. If it is in small fragments and it is calcined in a tube furnace or on a revolving hearth, by the aid of external heat. In either case the fumes are condensed in long brick flues and the arsenical "soot" is dug out and refined by resublimation; the refined product is "white arsenic."

If it is heated without access of air, the sulphide of arsenic (red) is sublimed.

Mispickel is not attacked by hydrochloric acid. It is decomposed by nitric acid, sulphur being liberated and the arsenic rendered soluble.

Mispickel often carries copper, silver, or gold. Copper may be tested for by adding ammonia to a nitric acid solution. Silver and gold should be tested for by first roasting the ore and then fusing with fluxes, as described under gold and silver.

The chief uses of arsenic are as follows:—A small quantity is added to lead for making shot. It is employed in dyeing. As arsenite of soda it is used as a spray for fruit trees.

"White arsenic" is employed as a poison for rats, mice and rabbits. Large quantities are used in the preparation of sheep dips and insect powders.

Germany is the leading source, but smaller quantities come from the U.S.A., Canada, Cornwall, Devon, Italy, etc.

White arsenic has been found native but not in sufficient quantities to make it of commercial importance.

Orpiment is a lemon-yellow semi-transparent mineral, containing about 60 per cent. of arsenic, the remainder being sulphur.

Realgar is an orange-red sulphide of arsenic, containing about 70 per cent. of arsenic and 30 per cent. of sulphur.

Neither of these minerals is of much commercial importance, as they have not been found in large quantities.

BARIUM.

*Barium.**—*Barytes*, or heavy spar, barium sulphate, and *witherite* barium carbonate, have both been described under "White Minerals."

Barium carbonate is of less frequent occurrence. It is employed in the refining of sugar, in the manufacture of plate-glass, etc.

The salts of barium are mostly prepared from barytes, converting it first to the sulphide by roasting with charcoal.

Barytes is found in many parts of the world. It is used as a paint by itself, when mixed with oil, and also to mix with white lead paint. Barytes has not the same "covering" power as white lead, but it has the advantage of not being blackened by sulphuretted hydrogen as lead paint is.

If barytes is pure and white in colour it requires no treatment, but if it is yellow or brownish (from traces of iron) it is sometimes cleaned by treatment with acid. When of good quality and colour and fairly free from impurities, it is worth about £1 5s. a ton.

The methods for the recognition of barytes and barium carbonate (witherite) have been already detailed under "White Minerals."

As the price is low, and the supply fully equal to the demand, any new discoveries would not be of much commercial importance unless they were extensive and of good quality, and well situated as regards easy mining and convenient access to rail or sea transport.

BISMUTH.

Bismuth.—Bismuth occurs native. It is found also as the sulphide, carbonate and oxide, all of which have been described.

The oxidised ores are likely to be found on the surface of an outcrop, and sometimes the metal or the sulphide is found in slugs or nuggets, embedded in an earthy matrix, containing a considerable quantity of carbonate and oxide.

The various ores are all easily reduced to metal by fusion with suitable fluxes.

Any compound containing bismuth (even if only very little bismuth is present) will yield a scarlet incrustation on heating some of the powdered mineral, mixed with sulphur and potassium iodide on charcoal.

Bismuth is chiefly employed in the preparation of cosmetics, and to a very large extent in medicine. It is a constituent of

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* Metallic barium can only be prepared with difficulty, and is merely a chemical curiosity. It oxidises in air and is decomposed by water.

"fusible metal" used for making safety plugs for steam boilers, and in alloys.

The price of the metal is at present 6*s.* 6*d.* per lb., and the production and sale are controlled. Both difficulty and risk therefore attend any attempt to place this mineral indiscriminately upon the market.

The annual consumption is estimated as not exceeding about 300 tons, it could be increased if fresh uses were found.

Bismuth behaves like lead on the cupel, that is to say, it is oxidised and sinks in; hence bismuth can be cupelled direct, to test for gold and silver, which it sometimes contains, but as it has the effect of causing any particles of gold or silver present to split up into a number of minute globules, it is advisable to transfer the button, before taken too far, to a fresh cupel with plenty of assay lead.

Some electricians have proposed to employ bismuth in the construction of storage batteries, and if a storage battery of practical utility were devised, the demand for the metal might be far greater than at present.

It is mined principally in Saxony, but occurs in small quantities in many parts of the world.

BORON.

Boron.—This non-metallic element does not occur native, and has no commercial application.

Boric acid, *sassolite*, is found native, and so is borax or "tincal," which occurs in certain lakes in Thibet. It is found also in Peru, California, Ceylon and other places.

The bulk of the Borax produced comes from the United States, chiefly California. In 1904 about 45,000 tons of crude material came from California alone; this material contains about 25 per cent. borax. Here it is made from a lime-borate, by a substitution process. Sulphurous acid decomposes the mineral and liberates boric acid. Borax is then made from the boric acid.

The world's annual production of borax is about 60,000 tons.

It may be detected by mixing the powdered mineral with Turner's mixture and igniting on a platinum wire. If boron is present the flame will have a distinct greenish tint.

Boric acid and borax are employed as food preservatives,[*] and are frequently added to milk, cream, butter, meat, etc., and as a flux.

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[*] Their indiscriminate use is objectionable, but is permitted by law in England in the case of cream and butter in certain stated quantities.

Commercial borax is about 99·5 per cent. pure, and should contain not more than ·3 per cent. of other sodium salts, and not more than traces of arsenic and the other heavy metals. For medicinal use and as a preservative it should be practically arsenic free, that is, it must not contain more than 1 part in 500,000.

Other minerals containing boron are :—Ulexite, calcium and sodium borate, boracite, borate and chloride of magnesium.

BROMINE.

Bromine.—This non-metallic element is only found as a very rare constituent in the mineral kingdom. The rare mineral named bromargyrite[*] is silver bromide.

It is a yellow or greenish-yellow mineral, and is found in certain parts of South America.

Bromine is a constant constituent of sea-water, and enters into the composition of all sea-weeds.

It used to be prepared from the ashes of seaweeds; it is now alsoextracted from the mother liquors of the Stassfurt beds. The nitrate of soda liquors in South America contain bromides, but there is no convenient method for extracting it.

Any bromide is recognisable by the brown irritating vapours[†] given off when it is warmed with sulphuric acid and manganese dioxide.

The uses of bromine are very limited. It has been employed with cyanide of potassium to extract gold from certain refractory ores and other chemical purposes. It has also been employed to a very limited extent as a disinfectant.

The bromides of potash, soda, and ammonia are employed to a small extent in medicine.

Bromides are usually found in conjunction with deposits of the nitrates of soda or potash, and of certain other alkaline salts.

CALCIUM.

Calcium.—Metallic calcium is only obtained with difficulty, and at present has little commercial use.[‡] It oxidises rapidly in air, and decomposes water, and is therefore never found native. In various combinations such as the carbonate, sul-

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[*] This mineral would be very valuable if found in a workable quantity.

[†] These vapours will *bleach* a piece of moist blue litmus paper, whereas nitrous fumes redden it.

[‡] It can be used to remove the last traces of air from a vacuum, as when melted it absorbs both oxygen and nitrogen very powerfully.

phate, phosphate, and in combination with alumina and silica, it is a very abundant constituent of the earth's crust.

Calcium carbonate occurs as marble, chalk, limestone, calcite, etc., which have already been described. "Iceland spar," which exhibits the curious phenomenon of double refraction, is a pure form of calcium carbonate.

All forms of calcium carbonate lose carbonic acid gas on ignition, and are converted into the oxide, which when moistened with water swells up and heats, and turns red litmus paper blue.

Calcium compounds when moistened with strong hydrochloric acid, and exposed to heat on a platinum wire, tinge the flame brick-red.

The colour imparted to the flame can be distinguished from that yielded by strontium and lithium compounds, by testing them side by side, and viewing each through a piece of blue glass; lime having a greenish appearance, strontium a violet or crimson tint.

All forms of calcium carbonate are dissolved by hydrochloric or nitric acid, with evolution of carbonic acid gas.

Marble is used for building, statuary, and as an ornamental stone. Chalk and limestone are burnt in kilns to produce lime for building and many other purposes.

Calcium phosphate is of value for the manufacture of phosphorus and as a manure. It has already been described under *Apatite* (*see* "Green Minerals").

In addition to the form known as apatite, it occurs under the forms known as osteolite, coprolites, phosphatic rock, and is an important constituent of guano. An impure form of calcium phosphate is produced as a by-product in the manufacture of steel from phosphoric pig irons; this is known as basic slag and is one of the cheapest sources of phosphate of lime available for agriculture, and deserves to be more widely used.

Phosphate of lime forms the mineral portion of bones, and bone-ash consists almost entirely of it.

Calcium sulphate, also known as gypsum and alabaster, is used for a variety of purposes.

When ignited and powdered it "sets" hard after being moistened with water, and is known under the name of "plaster of Paris."

Fluorspar, or calcium fluoride, is used for ornamental work, as a source of hydrofluoric acid and as a flux in smelting. In the smelting of certain ores, fluorspar is very useful as a flux, and would be worth a price that would vary according to its

purity and the ease with which it could be brought to the smelting works; nearly 100,000 tons are mined annually.

CARBON.

Carbon.—This element, in the form of carbonic acid gas, is found in the atmosphere in the proportion of about 4 parts of carbonic acid to 1,000 of air. Many carbonates are found native, such as the various forms of carbonate of calcium, the double carbonate of calcium and magnesium, carbonate of iron, copper, lead, zinc, barium, strontium, etc.

Coal and lignite are fossilised forms of vegetation. All vegetable matters contain more or less carbon in a state of combination, and when these are burned or decay the greater part of their carbon is converted into carbonic acid gas, which is eventually taken up by plants and becomes part of their structure.

The only forms in which carbon occurs free (or uncombined) in nature are as graphite and as the diamond. The latter has been described in the monographs on "White or Colourless Minerals," and graphite under "Black Minerals."

Graphite is largely employed in making crucibles, and for this purpose it must not contain a large percentage of ash, and the ash should be infusible.

Graphite is used for the manufacture of pencils, and for the preparation of antifriction compositions, and has other important applications in connection with electrical work. It is seldom found pure, and is usually mixed with some sort of gangue.

When dressed so as to be practically pure and free from foreign matter, it is worth some £12 a ton. As to the quality that would pay to mine, it would be necessary to test by experiment what degree of purity it could be dressed up to, and whether it were easy or hard to dress. Deposits of graphite, even of low grade, are deserving of careful attention.

The largest quantities are produced in Austria and Ceylon. The world's annual output is about 100,000 tons.

Coal and Lignite.—Lignite is a brownish form of coal, supposed to be a less compact form of coal and of more recent origin. Lignite is used as a fuel to a certain extent, but it is neither very plentiful nor very efficient as a steam-raising fuel.

Coal, on the other hand, is always an important mineral, and there can hardly be any part of the world where a discovery of coal would not have commercial importance, if the seam was of sufficient width and extent to work.

Coal may be divided into two principal groupings:—

(1) Anthracite;

(2) Bituminous.

1. Anthracite coal is usually iron-black, with a bright lustre and a conchoidal fracture. It is rich in carbon, containing from 88 to over 92 per cent. of carbon, and about 2 to 5 per cent. of ash. It yields very little smoke on burning. This is the type of smokeless coal used on war-ships.

It usually burns with a bluish and only faintly luminous flame. It requires to be burnt in a furnace, as it does not burn freely in an open grate.

Anthracite graduates through various varieties to bituminous coal.

Anthracite on carbonising yields but little gas, ammonia, liquor, and tar, compared with bituminous coal.

2. Bituminous coal.—This may be divided into three principal varieties:—Caking coal, non-caking coal, and cannel coal.

Caking or coking coal becomes pasty and coherent on heating, and the residue is a hard porous mass known as "coke." The types of coal used at gas-works are chosen both for the amount of gas they yield and for the character of the coke, which is sold as a slow-burning, smokeless fuel.

For steam-raising purposes a coal is preferred that does not burn too fast, and does not give off too much gas, *i.e.*, a coal rich in non-volatile carbon.

The commercial value of a coal depends much on the absence of such impurities as sulphur, phosphorus and ash, as well as on its caking properties and mode of burning, and its calorific value.

It is a remarkable fact that enormous quantities of coal are bought without being tested in any way, and without the purchaser having any real knowledge of the value or composition of what he is paying for. Thus, when coal is bought by or for the use of large public bodies, it is the exception rather than the rule for any test of it to be made. When large quantities are bought or tendered for, an estimation of the ash and of the calorific power ought certainly to be made, more especially as the choice between various tenders often rests in the hands of people who have no real knowledge. Nor in any case could a useful decision be arrived at by merely *inspecting* samples and prices: actual *tests* ought to be made of samples submitted, and the bulk should be required to be of the same quality as the sample. If this were done there is no doubt that better value would be obtained for the money expended.

CHLORINE.

Chlorine.—The chief compound of chlorine is sodium chloride or common salt. Rock-salt or halite occurs in large beds in England (Cheshire), in the United States, France, in Germany, India, and many parts of the world.

Common salt is the chief mineral constituent of sea-water. Salt is prepared from sea-water in some parts of the world by evaporation and then crystallising out the sodium chloride, and purifying by recrystallisation.

Rock salt is sometimes mined for, like other ores, but is also often extracted by pumping water into salt-mines and then pumping it out again and evaporating. It is also obtained by collecting it as it crystallises out naturally from salt-lakes, or "salt-pans," as in the Transvaal and at Salt Lake City, etc.

Refined salt is worth about £1 per ton, and any fresh discoveries would be well worthy of attention. Salt should be free from compounds of magnesia, which give it a bitter taste, like that of sea-water, which contains magnesia salts.

Chloride of potash (sylvite) and the double chloride of potash and magnesia (carnallite) are found extensively in the Stassfurt deposits. They are both valuable minerals, and any fresh discoveries would probably prove of great value.

In the event of its being desired to test a solution (for example, that of a native soluble salt) for chloride, bromides and iodides, the following method may be employed:—

Reduce the solution by adding a little granulated zinc and sulphuric acid. Warm till the zinc is dissolved, then divide the solution into three portions. To

1. Add a solution of silver nitrate; if a white curdy precipitate is produced, one or all of the halogens is present.
2. To another portion add ferric sulphate and warm slightly, then add a little carbon bisulphide and shake; if iodine is present it will colour the carbon disulphide purple.
3. To the third portion add chlorine-water and carbon bisulphide and shake; if bromine is present the carbon bisulphide will be coloured brown.

A quantitative separation of the three halogens may be based on these reactions. For example, by boiling a liquid containing all three, with ferric sulphate, iodine only is liberated, while by boiling the residual liquid with potassium permanganate the bromine is evolved before the chlorine.

CHROMIUM.

Chromium.—This element does not occur native. It may be prepared by reducing the oxide with charcoal at a very high temperature. The metal has no applications by itself, but is used to prepare chrome-steel, which is remarkable for its hardness.

Chrome-steel is used for the stamps and dies in batteries; nickel-chrome for armour plates; tungsten-chrome for tool steel; manganese-chrome for stone-breaker jaws and places where much abrasion takes place.

Ferro-chrome is made by reducing chromite in the electric furnace.

The ore, chromite, has been described under "Black Minerals." It is unaffected by acids, but can be decomposed, after fine grinding, by fusion with 4 parts of sodium peroxide to one part of ore.

If this reagent is not at hand, potassium bisulphate may be used, in the proportion of 1 part of ore to 10 parts of bisulphate.

Chrome-iron ore may contain alumina or magnesia. To be of commercial value[*] as an ore of chromium it must contain 50 per cent. of Cr_2O_3. Pure chromite contains 68 per cent. of Cr_2O_3. This ore is also used to a certain extent as a refractory material.

Picotite is a chrome spinel of no value.

The chromates of potassium and sodium are prepared by fusing the powdered ore with the carbonate of the alkali metal and a little nitrate.[†] The chromates are yellow and the bichromates are red. Both salts are employed in dyeing and in tanning leather.

Bichromate of sodium and of potassium are made by adding the requisite quantity of sulphuric acid to the respective chromates.

Lead chromate is prepared artificially, and is a bright canary-coloured powder; it is used for paint-making.

Native lead chromate, crocoisite or crocoite, has already been described.

Chromic acid, which is a crimson salt, crystallising in needles, and which absorbs moisture rapidly from the air, is prepared by adding a sufficient quantity of sulphuric acid to one of the chromates of the alkali metals to combine with the whole of the base.

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[*] Low grades that cannot be dressed up to a good percentage are of little or no value.

[†] The addition of a small quantity of nitrate is made to ensure complete oxidation.

About 75,000 metric tons of chromite are mined annually, the greater portion comes from the beach sands of New Caledonia, but it is found in many other parts of the world.

The surface of ore that has been exposed to the weather is sometimes coated with a dull greenish stain of chrome ochre.

The value of chromite is about £3 to £4 a ton for ore containing 50 per cent. of Cr_2O_3.

COBALT.

Cobalt.—This metal is not found native ; it can be prepared by the reduction of its oxide with charcoal at a high temperature. The metal has no commercial applications.

The principal ores, namely, smaltite, cobaltite and erythrine, have been already described. Asbolan, a variety of psilomelane carrying cobalt oxide in variable quantities, has been mined, but is not now of much importance.

Cobalt is used to impart a blue colour to glass, and the artificially prepared oxide, smalt, being a bright blue, is used as a pigment.

Cobalt ores were mined until recently in Sweden, but the large find of argentiferous erythrine at Cobalt City will probably be sufficient to supply any possible demand for a long time to come. This find is so extensive that any fresh discoveries of cobalt ore would be of small importance.

Erythrine should always be examined for silver, as the deposits found at Cobalt City are rich in silver.

COPPER.

Copper.—Copper ores are found in England, most European countries, America, Australia, Canada, Africa, etc.

Copper occasionally occurs native, sometimes as oxide, sulphide, carbonate, silicate and oxychloride, but usually as the double sulphide of copper and iron.

Copper carbonate is of a green or bluish colour; when in a compact form it is known as malachite, azurite, etc., and when capable of taking a polish is valuable for lapidaries' work.

Copper carbonate is usually due to decomposition of sulphide of copper, and is often found on the upper portions of a lode of which the lower part consists of sulphide.

Copper sulphide when near the surface usually decomposes, sulphate, carbonates, or oxides being formed under varying conditions. Some compounds being soluble in water may be carried some distance from the original lode and redeposited in differing combinations. Incrustations with copper carbonate are met with containing varying percentages of copper; anything over 2 or 3 per cent. would be worthy of consideration.

The chief ores are chalcopyrite, copper glance, "peacock" ore and fahlerz. The so-called "peacock" copper ore is the ordinary copper pyrites (which is normally yellow when freshly broken from the lode). When exposed to the air it sometimes becomes coated with an iridescent layer having a brilliant purple tint, hence the name "peacock copper ore."

Metallic copper is obtained commercially by partially roasting the pyrites, forming a matte, and then "Bessemerising," or re-roasting to oxide and smelting with anthracite. The metal is worth about £60 per ton. The world's consumption is about 800,000 tons.

The objectionable impurities in metallic copper are arsenic, antimony, bismuth, tellurium and zinc which cause it to become brittle. Electrolytic copper is in great and growing demand for electrical work.

Sulphate of copper is largely used by agriculturists and gardeners for spraying crops and fruit trees, dressing seed corn as a preventive against rust, etc. The demand is increasing.

Copper often carries small quantities of silver and gold, and when the percentage of these metals is appreciable they are extracted.

Copper ore would probably pay to work if it contained 2 per cent. of metal, provided that it could be concentrated* and that other conditions were favourable.

Most of the ores are distinctive in appearance, and all of them heated before the blow-pipe with cyanide yield the metal.

Silicate of copper is usually greenish in appearance, it is decomposed by hydrochloric acid and sulphuric acid (*see* Chrysocolla).

Both oxide and carbonate are soluble in most acids, forming a green or blue solution.

An iron pyrites carrying a small quantity of copper might possess a commercial value even though it did not contain a large enough amount to smelt direct. It is well, therefore, in testing pyrites to treat the roasted ore with nitric acid; if copper is present it will dissolve, forming a bluish-green solution.

In the dry assay of copper we must consider which class the ore is:—

1. Rich oxidised ore.
2. Copper and iron sulphide.
3. Rich copper with insufficient iron to form a regulus.

Carbonates, oxides, and silicates can be reduced to the metal by direct fusion with carbonate of soda and "black flux" in an ordinary crucible.

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* The carbonates cannot be concentrated with water like most metallic ores, on account of their low gravity and tendency to "slime."

Sulphide of copper and sulphides of iron containing copper must first be melted with a fusion mixture so as to obtain a button of copper sulphide.

This compound of copper and sulphur may contain from 10 per cent. to 60 per cent. of copper, and is called a "regulus" or "matte."

This button is powdered and placed in a crucible maintained at a low red heat, and roasted with free exposure to air till the sulphur has burned off, which may take an hour. The powdered material is stirred every few minutes with an iron rod, and when the sulphur has burned off, and the contents on the crucible, being removed from the fire for a moment, no longer give off a smell of burning sulphur, a little charcoal is added to decompose any sulphates that may be present, and the roasting continued for a few minutes.

Then "black flux" is mixed with the contents of the crucible previously cooled, and heated strongly till reduction is complete.

The results of an assay carried out in this manner will be some 2 per cent. below the truth, on account of copper retained in the slags. If these are re-treated part of this loss will be recovered.

Copper ores may carry gold or silver, and the button of copper obtained should be dissolved in nitric acid. Any black powder should be filtered off and tested for gold, and the solution should be tested for silver by adding a drop or two of hydrochloric acid; if there is any precipitate, the liquid is diluted, and a small quantity of lead acetate solution is added, and a few drops of sulphuric acid. It is allowed to settle for some hours, filtered, and the filter paper and precipitate dried, wrapped in a piece of lead foil, scorified, and cupelled.

A convenient rough method of recognising the presence of copper, in the absence of apparatus and chemicals, is the following: Grind the ore as finely as possible, add a little powdered charcoal, and roast the mixture at a red heat on a frying-pan or shovel till all volatile matters have been burnt off. Then place the roasted ore in a plate and pour enough vinegar, or any acid, on it to partly cover it. After keeping for about 24 hours the liquid will be bluish or greenish, and will deposit a copper stain on a clean knife-blade.

Grey copper ore is attacked by nitric acid, forming a green solution. The blow-pipe test will at once reveal the presence of copper.

Iron pyrites is of a paler yellow colour, and must not be confused with copper pyrites. It is much harder and can be cut only with difficulty with a knife. Copper pyrites can usually be cut more easily, but the author has found samples of

iron pyrites rich in copper, which were remarkably resistant to the knife-blade.

Many deposits of iron pyrites carry a certain proportion of copper, with traces of gold and silver, and when iron pyrites is used as a source of sulphur (in the manufacture of sulphuric acid) the burnt ore is frequently treated to recover the copper and the traces of the precious metals.

Atacamite, or copper oxychloride, consists of a combination of copper chloride with two molecules of hydrated copper oxide. It is soluble in hydrochloric and other acids. If heated before the blow-pipe on charcoal, copper chloride is volatilised; as it volatilises it colours the flame blue and an incrustation is produced on the charcoal; this incrustation consists partly of copper oxide (brown) and partly of the chloride (grey). On further heating the grey incrustation is volatilised and the copper oxide is converted to metallic copper. This requires a rather prolonged blow-piping at the full heat of the reducing flame.

On account of the volatility of copper chloride, atacamite cannot be smelted direct, but requires treatment by a special, though not complicated, process.

Chrysocolla, or copper silicate, is usually green, but sometimes bluish or brownish. "Pitchy copper ore," an impure variety, is blackish-brown. On treatment with hydrochloric acid chrysocolla is decomposed into silica and copper chloride, giving a greenish-blue solution.

Dioptase is also a silicate of copper, of a greenish colour, more or less transparent. It is decomposed by hydrochloric acid.

Tennantite is a compound containing copper, sulphur and arsenic.

Cement Copper.—The water from copper mines sometimes contains copper in solution in sufficient quantity to render its recovery commercially possible.

It is then treated in tanks with scrap iron. The copper in solution, whether existing as chloride or sulphate, becomes converted into metallic copper, and a proportionate amount of iron goes into solution. The precipitate, or "cement copper," so obtained is naturally contaminated with impurities to a large extent, and may contain as much as 80 per cent. to as little as 30 per cent. of copper. Copper sulphate can be decomposed electrically, but the amount deposited is so small in proportion to the current required that it would only be an economical method to employ where water-power on a large scale was available.

Assay of Copper Ores (Iodide Method).—The ore is ground to pass 80 mesh.

Weigh out from 1 to 5 grams (according to richness) into a conical beaker, and decompose with nitric acid. Evaporate to dryness. Take up with 30 c.c. dilute sulphuric acid (1 : 4) and boil down till white fumes of sulphuric acid are given off. Cool, cautiously dilute and filter. Dilute to about 200 c.c. with water. Boil, and pass sulphuretted hydrogen until precipitation is complete. Filter and well wash with hot water acidified with sulphuric acid, and containing a little sulphuretted hydrogen, until washings are quite free from iron. (This is tested by adding a drop or two of the washings to a small quantity of potassium ferri-cyanide solution; iron is indicated by a blue colouration.) Wash back precipitate into flask, and boil down with 15 c.c. nitric acid until quite decomposed. Add a little water, and boil until free from nitrous fumes. Neutralize with sodium carbonate, avoiding excess, acidify with acetic acid. Add 5 grams of potassium iodide, and dilute to 150 c.c. Add 2 or 3 c.c. of "starch solution,"[*] and titrate with a standard solution of sodium hyposulphite.[†]

FLUORINE.

Fluorine.—The two chief compounds of fluorine are fluorspar and cryolite.

The former mineral is fairly widely distributed. It often occurs in company with lead ores and (though not so much in England) in company with cassiterite.

Fluorspar is of many different colours, perhaps white is the most common, but it may be purple, blue, rose-red, bright red, yellow, green, brown, or colourless.

The specific gravity is slightly higher than the majority of rocks, being a little over 3·0. Most specimens are only moderately hard, that is, they can be scratched by a knife. There are also softer varieties. All are alike decomposed when heated with strong sulphuric acid, with evolution of hydro-fluoric acid. If the heating is done in a platinum or lead dish, with a glass slide on the top coated with wax, on which some device has been scratched so as to expose the glass, the etching effect is well seen. Fluorspar is sometimes used for the manufacture of ornaments, but its chief use is as a flux in smelting.

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[*] Starch solution is made by mixing a little starch into thin paste with water, and adding a few c.c. to 250 c.c. boiling water. Boil for a minute, and cool before use.

[†] The standard solution of sodium hyposulphite is made by dissolving 39·18 grams of the pure salt in water, and diluting to a litre; 100 c.c. should be equivalent to 1 gram of copper.

This is standardized by weighing out from ·25 to ·5 gram of pure electrolytic copper, and dissolving in 5 c.c. nitric acid, and proceeding as in assay (after separation of the copper).

Fluorspar decrepitates on heating, and most specimens emit a phosphorescent light when put in a dark place after having been heated.

It melts before the blow-pipe to a clear glassy bead, which turns white and opaque when cold.

Cryolite, a mineral found almost exclusively in Greenland, is a double fluoride of aluminium and sodium. It was largely used in the manufacture of aluminium by the sodium process, but now that electrolytic methods are employed it is of less commercial importance.

It has been described under "White Minerals."

It is a more or less transparent mineral varying in colour from white to brown, reddish brown, etc.

It is soft, easily cut with a knife, and so fusible that it will melt in any flame without the aid of a blow-pipe.

Like fluorspar, it yields hydrofluoric acid when heated with sulphuric acid, but is also decomposed partially when heated in an open tube, and if the blow-pipe flame is allowed to play on it, a perceptible etching of the glass will be noticed.

There are also forms of apatite (native calcium phosphate) which contain fluorine, and, in addition, certain of the minerals of the rare earths also contain fluorine.

GOLD.

Gold.—Gold is found in every continent.

It almost always occurs native, and frequently as "visible gold." If not visible in the rock it is usually so on crushing and panning.

Where suitable crushing appliances, such as a steel mill or mortar,[*] are not to be had, small quantities of rock may be reduced to powder by heating red hot and plunging into water, when they usually are brittle enough to powder with a hammer or axe-head.[†]

Except in the case of exceptionally hard or tough ones, it is usually possible to reduce stones to powder by rubbing them on a large flat stone, using a smaller one as a muller.

For breaking up moderate quantities of any ore by hand, a panclast is very convenient.

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[*] A sawn-off wrought iron mercury bottle makes a handy little mortar, but it must be heated to a red heat before it is used to get rid of the mercury that generally sticks in it.

[†] This plan of burning stones to make them brittle is useful in all cases where the mineral is not decomposed by heat.

When in the form of nuggets gold is, of course, unmistakable, but, when disseminated through a rock in small flakes, it may sometimes (especially by inexperienced persons) be confused with pyrites and mica. It is at once distinguished by applying the point of a knife or needle, gold being *soft* and pyrites brittle, while mica washes away in the pan.

In the absence of materials for a fire-assay, very useful results can be obtained by "panning." This art is quickly acquired, at any rate to the extent of being able at once to demonstrate the presence of the metal and to obtain a fair estimation of its amount. Of course, only the free gold (*i.e.*, that which is in the metallic state and not enclosed in pyrites and iron oxide) will be obtained in this way.

In a district in which the prospector has proved the presence of gold, he should be very careful to examine everything, for the reason that gold is often found in stones, rocks and formations of an unpromising appearance.

Some prefer to pan off the greater part of the gangue (earth or sand), and having obtained the gold in a fairly pure condition, to add a small quantity of mercury, which will amalgamate with the gold, and so avoid or minimise the loss of gold. The mercury is then distilled off by heat in a retort and the gold left behind. The gold is then smelted with borax and nitre to purify it.

Free gold in lode-stuff is extracted by milling and amalgamation. The ore is crushed in a stamp-mill, and the pulp flows over copper-covered tables coated with mercury. The gold, or rather that proportion which is "free-milling," adheres to the mercury on the copper plate, and forms "amalgam," which is removed by scraping from time to time, and the gold recovered by distilling off the mercury, which is condensed and used again.

The "tailings" which pass over the plates should (if the mill is properly managed) contain but little free gold, but they nearly always contain a certain amount of gold enclosed in or adhering to particles of gangue, which might or might not be released by finer crushing.

"*Flouring*" *of Mercury.*—When gold is accompanied by pyrites to such an extent that the mercury on the plates would be "floured" or "sickened," it is sometimes necessary to use "blankets" of some felt-like material, and not amalgamated plates.

The tailings consist of sand and slimes, and should be examined to see whether they will pay for treatment. When the milling of gold ores is first begun, it sometimes happens that valuable tailings are allowed to flow away. They should always be saved, as scarcely any tailings from a gold mill are

incapable of being profitably treated, if proper methods are used, which may or may not include the preliminary concentration of these tailings.

Gold Dredging.—In gold-bearing districts the streams and rivers and the sites of old water-courses should be carefully examined for gold.

Very much smaller quantities of gold will pay when it can be obtained by dredging or sluicing than if it has to be mined and extracted from lode-stuff.

Four pennyweights to the ton can, under certain circumstances, be profitably worked in lode-stuff that has to be stamped, but a few grains will pay if conditions are favourable for dredging.

The following points are important in considering a dredging proposition :—[*]

1. Is the earth or sand free from large rocks or snags?
2. Is there a constant supply or water all the year?
3. Are violent floods common?

Before concluding that any considerable outlay ought to be undertaken, several hundredweights of the earth or sand, fairly sampled, should be panned down and assayed.

This can usually be done on the spot, and the concentrates obtained on panning should be smelted with litharge, borax, &c., and the lead button containing the gold cupelled, or the concentrate may be amalgamated by grinding with mercury. In any case, an average portion of the concentrates should be tested by fire-assay.

It is very easy to make an assay of gold concentrates by scorification with lead and cupelling the resulting button on a bone-ash cupel. In default of a proper cupelling muffle, the cupel can be placed just inside any furnace (a steam boiler furnace, for example), but there must be a sufficient supply of air to oxidise the lead.

Gold also occurs in ores in combination or mixtures of such a nature, such as tellurides, that it is not recognisable on panning, and therefore if its presence is suspected, or if pyrites or other ores are found in a district where gold is known or suspected to exist, it is advisable to attempt a rough assay which may be conducted as follows :—

First grind the ore to pass a 60-sieve and roast in a clay dish or crucible with free exposure to air.

Then fuse with a suitable quantity of fusion mixture (sodium carbonate, borax, etc., and litharge) with a reducing agent (charcoal or flour).

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[*] When a concentrate from an alluvial deposit is being assayed, a look-out should be kept for platinum, iridium, osmiridium, cassiterite, etc.

The following general receipt will serve for the assay of gold ores of a quartzy nature :—

50 grams of ore (carefully sampled and reduced to an 80 powder[*]),
30 grams of litharge or red-lead,
75 grams of carbonate of soda,
25 grams of borax,
1½ grams of charcoal (or 3 grams of flour).

These should be well mixed and fused until the contents of the pot are tranquil.

If the gangue is chiefly silica this mixture answers well, but if much sulphides are present in the ore it may be roasted first and then cooled and mixed with the fluxes. In which case the proportion of carbonate of soda is decreased, and the proportions of borax and charcoal increased, or some nitre may be added, to affect the oxidation of the sulphur, or a piece of hoop-iron is sometimes added to counteract the effect of the sulphur on the lead, when the proportion of sulphides in the ore is not very great. If there is a large quantity of iron, a small quantity of silica (clean powdered quartz-sand) should be added in addition to the above fluxes, which will serve to flux the iron.

The button of lead obtained is then cupelled on a bone-ash cupel. If a forge-fire is obtainable a fusion can be performed without the use of a regular assay furnace, or a portable charcoal furnace may be used.

This consists of a light cylindrical fire-clay furnace which burns charcoal and is supplied with an air blast so as to obviate the need of a long chimney.

Bone-ash cupels [†] can be easily made anywhere. Some clean bones are reduced to ashes by placing them in a clear fire. After being burnt white and cooled they are ground to pass a 90-mesh screen, just very slightly damped with water and pressed into shape in a cupel mould. After drying slowly for 24 hours they should be gently heated and any that crack discarded.

The cupellation can be performed in the same furnace,[‡] by placing the cupel either on a fire-tile or inside a crucible.

The cupel is placed in the furnace till it is red hot, then the lead button is put on it previously hammered to remove any adherent slag.

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[*] If coarse gold is present, the difficulty of getting an accurate assay is considerable, and several assays must be made and the average of them taken. Particular care must be taken to see that coarse gold does not stick in the mesh of the sieves.

[†] While home-made cupels answer when machine-made cupels cannot be obtained, the latter are preferable because they are stronger and do not break in transport. The morganite cupels have proved very satisfactory.

[‡] If a proper muffle-furnace is not available.

In cupelling, a bright red heat is necessary. The lead is converted into litharge, and is absorbed by the porous cupel. Pure assay lead should be practically free from silver; if ordinary lead or litharge is used a small quantity of silver will be left on the cupel. The lead from tea chests contains only traces of silver, and is suitable for assay work. In any case, the lead or litharge used must itself be assayed for silver, and the necessary allowance made.

If a bead is seen after the operation and is white and very minute, it is probably only the silver present as an impurity in the lead. If the bead is yellow and is malleable, it is mostly gold. A silver-coloured bead may consist chiefly of silver, but a large quantity of gold may be present without the yellow colour of gold being visible.

If a silvery bead is found, flatten it and dissolve in nitric acid. Beads containing much gold cannot be successfully "parted," and some pure silver should be added and fused with them. Any gold will remain as an insoluble black powder, which if collected, dried and heated, assumes the usual gold colour.

Should platinum be present with the gold, the bead presents a crystalline appearance.

Gold and platinum (and to a less extent silver) are so valuable that even very small quantities may prove of high value, and therefore, if there is any probability of the presence of any of these metals, a thorough examination is advisable.

The portable fusion furnace (which can also be used for cupellations) is constructed of fire-clay in sections bound together with iron.

It is made without a chimney for portability, and the necessary heat is obtained by the aid of an air-blast from a foot-bellows. As charcoal burns away rapidly the crucible is not supported on the fuel itself, as is customary in a coke furnace, but on another crucible turned upside down. Fuel can be fed in without displacing the crucible, and the contents of the pot can also be watched through the hole at the top.

The method of using the furnace is as follows:—

Place it on a level surface and bank round with earth or sand to retain the heat. Protect it from rain.

Place a crucible and some dry leaves or twigs in the furnace, light them and add sticks and charcoal. When these are well alight fill up with charcoal, put on the top of the furnace and connect the rubber tube from the foot bellows to the nozzle of the blast. In a few minutes the furnace will be red hot internally.*

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* When there is no hurry the furnace should be lighted and two or three crucibles placed in it and the whole heated gradually two or three hours before using.

The furnace is specially designed to work with charcoal, as it can be obtained or made in remote places where coke or liquid fuels cannot be had. It is useful for sharpening picks and drills as well as for assay work.

Natives in most parts of the world are accustomed to make charcoal, but if there is any difficulty in obtaining it, the following method will be found convenient.*

Dig a pit 4 feet deep, 4 feet wide, and 8 feet long. Arrange a trench 1 foot wide and 6 inches deep running along the middle of the bottom. Place a layer 1 foot deep of twigs and small brushwood in the bottom of the pit, leaving the trench clear. Over the brushwood place logs up to 2 feet 6 inches thick and 2 or 3 feet long till the pit is filled level with the ground. Light a fire in the trench at one end and allow it to get well alight. Then cover the whole pile with twigs, leaves, and finally earth. Regulate the fire by admitting or excluding air so that the process of carbonisation is complete in about three days; when about half a ton of charcoal should be obtained. Choose, if possible, hard, heavy and sound wood, stripped of bark —the heavier the wood the better the charcoal.

The preparation of cupels should be undertaken at the same time that the charcoal is being made, as they should have a day or two to dry before use, otherwise they are liable to split on heating.

In the case of gold and of silver ores the relative proportion of metal is so small to that of the matrix in which it is distributed, that to obtain the metal by a fusion assay it is necessary to add another metal to collect the minute particles of gold or silver. The metal most suitable for this is lead, which is added in the form of litharge, accompanied by such reducing agents as will result in the greater part of the litharge being reduced to metal. If litharge is not available, metallic lead may be used. Suitable fluxes must also be added in order that the rock in which the gold or silver occurs may flux or flow readily, *as the success of the operation depends on each minute particle of the precious metal coming in contact with and being dissolved in the minute globules of lead which first traverse the whole melted mass and finally collect at the bottom.*

The melted mass is finally poured out into a cast-iron mould and when it is cold the lump is hammered to cause the button of lead to separate from the slag, which it should do without leaving particles of lead adhering to it. The slag

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* In many countries charcoal can be obtained from the partially burnt logs after bush fires.

should pour readily. If the rock was nearly pure quartz, the slag will be of a pale green tint; if much iron was present it will be brown, dark green or black.

The fluxes that are ordinarily employed are carbonate of soda and borax. The former of these is used to cause the silica (which usually forms a large proportion of the rock, and which is infusible at any ordinary heat) to be converted into sodium silicate, which melts easily; the borax, which melts at a low red heat, also promotes the fluidity of the charge. When sulphides are present in considerable quantity, as sometimes is the case, the ore must either be first roasted to destroy them or they must be destroyed by adding an oxidising agent, such as nitre, to the charge.

It is essential to obtain readily fusible slags, because otherwise particles of gold or silver might be retained in the slag.

The progress of the fusion can be seen by watching the contents of the pot before removing it from the furnace.

Towards the end of the operation the fused mass should be tranquil and uniform and not show small particles floating about in it.

The tellurides containing gold are considered separately under "Tellurium;" they are rare, but of great importance on account of the large proportion of gold that they contain. Further information on the metallurgy of gold will be found in the Appendix.

The world's production is about 22,000,000 ounces annually.

IODINE

Iodine.—This element is widely distributed in nature, but for the most part in very minute quantities. It occurs in minute quantities in the ashes of land-plants, and to a much greater extent in the ashes of sea-plants, certain varieties of seaweed having the property of accumulating it from sea-water, which always contains it in varying quantities.

Formerly iodine was prepared commercially by lixiviating the ashes of a particular kind of seaweed, known as "kelp." Both iodine and bromine were obtained in this way.

Nowadays iodine is extracted from the mother-liquors after the extraction of nitrate of soda, and from the mother-liquors from the deposits of potash salts at Stassfurt. Iodine always commands a high price, though its applications are not very numerous.

The price is controlled by arrangement, and in order to maintain the price the production is restricted. A considerably larger

quantity could be prepared from the liquors above mentioned, a large part of which are allowed to run to waste.

Iodine occurs in combination with silver, in a few localities as iodargyrite, a yellow or yellowish-green mineral, and in one or two other rare minerals, but does not occur in payable quantities, except in the nitrate of soda and the potash deposits already described.

IRON.

*Iron.**—This metal is widely distributed over the whole world in the form of various oxides. Ordinary earth and many rocks owe their brownish colour to oxide of iron.

The chief ores of iron that are mined for the purpose of making iron and steel are as follows:—

1. Hæmatite, including micaceous iron ore.
2. Limonite, gothite.
3. Magnetite.
4. Chalybite or siderite (spathic iron ore).
5. Clay ironstone, argillaceous hæmatite.

Bog iron ore, an hydrated oxide, is used for purifying coal gas. It is worth about 30s. a ton in England.

All iron ores and most compounds containing iron are dissolved in or decomposed by hydrochloric acid; some are readily acted on in the cold, others require fine grinding and treatment with hot strong acid for a considerable time and under pressure. They dissolve yielding a yellow solution. On the addition of ammonia, the iron is thrown down as hydrate, a flocculent brown precipitate.

In the borax bead, iron ores yield a yellow bead in the oxidising flame and a bottle-green in the reducing flame.

Hæmatite.—Dull red, sometimes crimson (earthy forms), steel-grey or black (massive). It has a gravity of about five (or 4·5 earthy varieties) and can be scratched with a knife. The streak is red or reddish-brown. It is the chief iron ore used by smelters for the production of pig-iron, but to be of commercial value must contain but little sulphur, and only a small quantity of siliceous or other gangue.

Limonite.—Is usually brown with a light-brown streak, and is called "brown hæmatite." It has to be calcined before smelting, to expel the water it contains, in which respect it differs from hæmatite.

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* Meteorites, which are occasionally found, consist chiefly of metallic iron and possess a value for collectors.

Heated before the blow-pipe on charcoal in the oxidising flame, it blackens and forms a magnetic oxide which is attracted by a magnet.

In the borax bead test, evidence is obtained of iron.

It dissolves in warm hydrochloric acid to a yellow solution, and on the addition of ammonia the iron is precipitated as hydrate, a flocculent brown precipitate.

The value of an iron ore, for smelting purposes as a source of iron, depends upon the amount of sulphur and either absence or abundance of phosphorus, and for this reason pyrites and similar minerals containing sulphur are not considered here, but under "Sulphur."

The ore, in addition, must contain little silica, as it has to be practically pure to be worth considering. It must occur in very large quantities, and if not smelted on the spot, transport must be very economical.

The metallurgy of iron and steel is such a vast subject that it is impossible to dwell upon it in these notes, beyond rapidly describing the chief differences between cast or pig iron, soft iron and steel. Pig-iron is the first product from the blast furnace in which the ore has been reduced at a high temperature with suitable carboniferous fuel, and contains a high proportion of "free" and "combined" carbon in indefinite quantities and other impurities, which render the iron very brittle. To get rid of these impurities and to manufacture steel, the pig is transferred to a "converter," and while in a molten state a blast of air is blown through it which oxidizes the various impurities, in order of their oxidizability. These impurities act as fuel, and combining with oxygen keep up the temperature of the mass and keep it molten. Steel contains a certain amount of carbon, which is added to the converter as a ferro-carbon alloy after the other impurities have been eliminated. Small quantities of some other metals are introduced into the steel in varying proportions for the purpose of hardening and toughening it; notably, manganese, chromium, nickel and tungsten, and sometimes titanium, molybdenum, vanadium, tantalum. Most steel contains also a little silicon.

LEAD.

Lead.—Lead ores are found in England, Spain, America and Australia and elsewhere. Lead is one of the most frequently occurring metals. The metal is not found native.

The principal ore is galena, or lead sulphide. The carbonate, sulphate, oxide, chromate, are occasionally found, but galena is the principal ore.

Galena always carries a certain percentage of silver, and when it contains from 10 oz. per ton or upwards the metallic lead is

treated by various processes to obtain the silver. The appearance of a sample of galena affords no indication as to the presence or proportion of silver present, although often the finer grained varieties contain more than the coarse grained specimens. This is, however, not necessarily so.

Galena is usually easily recognisable by its appearance. It is of a bright lead grey colour with metallic lustre. It usually occurs massive; it is crystallised in cubes, and is very readily reduced to powder. Heated on charcoal the sulphur burns off, and is readily converted into the metal by heating in the reducing flame of the blow pipe; the bead is soft, is easily cut with a knife and marks paper. A yellow incrustation of lead oxide is also formed, a little distance from the test. Lead has a very wide application in many industries, and, as it occurs in most countries in considerable quantities, is a comparatively, cheap metal.

Pig lead is now worth about £13 a ton. In 1906 it rose considerably in price.

Deposits of lead are only commercially workable when they occur in considerable quantity or under conditions favourable as regards water-power, labour, etc. If a deposit of galena is discovered some of the ore should be reduced by mixing with an equal weight of carbonate of soda and a little borax in a clay crucible with a piece of clean hoop-iron rolled up, and heating to a red heat.

The galena will be reduced to the metallic state; after weighing the button, it should be cupelled to ascertain whether the ore carries appreciable quantities of silver.

Native Carbonate of lead, or cerussite, is white or yellowish grey in colour. It is the only carbonate not soluble in HCl. When pure it has a specific gravity of about 6·5. It is soft and can be cut with a knife. Heated alone on charcoal before the blow-pipe it does not melt, but gives a yellow incrustation, and in the reducing flame is reduced to metallic lead.

Native oxide of lead, or minium, varies in colour from a bright red, that might be mistaken for cinnabar, to a dull red or brown colour similar to haematite. The oxide is easily reduced to a bead of metal in the reducing flame.

Native sulphate of lead, anglesite, has a specific gravity of about 6·2. When heated before the blow-pipe it melts on ignition in the reducing flame, giving off fumes of sulphurous acid.

Anglesite is not soluble in hydrochloric acid, but dissolves in aqua-regia.

Native chromate of lead, or crocoisite, is orange-red in colour; it is soluble in aqua-regia.

Its specific gravity is about 6.

Heated before the blow-pipe it deflagrates and a bead of lead is formed, together with an incrustation of chromium oxide.

All the above minerals may carry silver and should be assayed for that metal.

The world's consumption of lead is about 1,000,000 tons yearly.

It is used as sheeting, piping, projectiles, in the manufacture of white and red lead and paints, and for many other purposes.

LITHIUM.

Lithium.—Lithium is a soft, silver-white metal which rapidly oxidises in air and is decomposed by water; hence it is not found native, and has no commercial applications.

It is somewhat widely distributed in nature, being found (in small quantities) in the ashes of plants and in certain mineral springs.

The chief minerals containing it are, *lepidolite*, which has already been described under "Red Minerals," *spodumene* and *petalite*, *amblygonite*, and *triphylite*.

Lepidolite is the chief of the lithia minerals, and contains from 2 to 5 per cent. of lithia. It is found in Maine, Connecticut, Massachusetts, Sweden, Bohemia, Saxony, Cornwall, etc.

The chief salt used is the carbonate, which is prepared chiefly from lepidolite, also from spodumene, triphylite, etc. By fusion and extraction the chloride is first obtained; this is then converted into the carbonate, by treatment with sodium or potassium carbonate. In some cases the finely powdered ore is treated direct with hydrochloric acid.

Spodumene is usually a greyish-white or greenish-white mineral, consisting essentially of a double silicate of alumina and lithia. Other colours are also known, such as the green or yellowish-green variety known as *Hiddenite.*

Spodumene is hard, its specific gravity is a little over 3·0, it is unaffected by acids.

Before the blow-pipe it turns white, becomes opaque and swells up. At the moment of fusion it communicates a purple-red tint to the flame.

This is better seen by mixing the powdered mineral with Turner's mixture* and igniting on a platinum wire.

Spodumene contains about 8 per cent. of lithia.

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* One part of powdered fluor-spar and four parts of potassium bisulphate.

Petalite is usually colourless, white or grey; its streak is colourless. It is hard and brittle. Its specific gravity is about 2·4.

Like lepidolite and spodumene, it is not acted on by acids, but the flame coloration is readily obtained by the use of Turner's mixture.

It contains about 5 per cent. of lithia.

Zinnwaldite is a rare mica consisting essentially of the silicates of iron and lithia. It is usually grey or brown, soft enough to be scratched by a knife. Its specific gravity is about 3·0. It melts before the blow-pipe, giving a red-flame coloration.

Uses of Lithia Salts.—"Mineral waters" containing lithia are bottled as medicinal table waters.* The salts of lithia, particularly the citrate and carbonate, have a limited use in medicine.

MAGNESIUM.

Magnesium.—This element is not found native, but is prepared artificially by decomposing the chloride with sodium. It is employed in ribbon and in powder to produce a brilliant white light in pyrotechny and for signalling.

Magnesium sulphate exists in sea-water, and gives it its bitter taste.

The sulphate (known as Epsom salts) exists in certain springs, and is also prepared artificially by decomposing the carbonate (magnesite) with sulphuric acid.

Dolomite is a rock consisting of the carbonates of calcium and magnesium.

Magnesite, the carbonate, is described under "White Minerals." It is found chiefly in Austria, Greece, Hungary, Transvaal, etc., and is worth about 1*l.* 10s. (calcined) per ton.

Serpentine, a rock used for ornamental work on account of the good polish and ornamental colours it possesses is essentially a silicate of magnesium with some iron (and sometimes chromium).

The colour is frequently a light green or blackish-green, also a brownish-red. The streak is nearly white and shining. It can be cut with a knife. The fibrous variety is known as chrysotile.

The substance known commercially as asbestos is sometimes chrysotile and sometimes a calcium-magnesium silicate. Asbestos is valued for its infusibility and its property as a non-conductor of heat.

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* Some of these are natural mineral water, but most of the "lithia water" sold is ordinary water to which a small addition of lithia salt has been made.

When the fibres are long enough it is woven into a fire-resisting cloth; the shorter fibres are used for lagging boilers, making fire-resisting panels for rooms, etc.

A discovery of asbestos in long fibres would be of considerable value.

Talc, steatite, and soapstone are chiefly silicates of magnesium.

Talc occurs in flexible sheets having a rather greasy lustre. It is soft enough to be scratched by the finger-nail. Large sheets are valuable. The principal supply comes at present from India.

Steatite and soapstone are a whitish rock with a greasy feel; it has been described under "White Minerals." It is also soft. It is used as a lubricant under the name of "French chalk." It is worth about 30s. per ton.

Meerschaum (sepiolite) is also a hydrated silicate of magnesium, and is used for the bowls of tobacco pipes.

MANGANESE.

Manganese.—The principal ore of manganese is the dioxide, *pyrolusite*, which has already been described under "Black Minerals."

Psilomelane and *Wad* are hydrous oxides of somewhat indefinite composition, and usually containing earthy impurities and admixtures of other metals. They are not of much commercial importance.

Asbolan is a dark black-blue mineral usually earthy in appearance; it consists chiefly of manganese oxide with varying amounts of oxide of cobalt.

One of the chief uses of manganese is for the manufacture of ferro-manganese, an addition of which is made to "Bessemer" and open-hearth metal as a deoxidiser and recarburiser. In fairly large quantities it confers valuable properties to steel such as toughness, etc.

Manganese and copper constitute "manganese bronze," which is largely employed for steamers' propellers.

Pyrolusite is used as the source of manganese salts, such as the manganates and permanganates, which are still used as disinfectants, though they have scarcely any action at all on bacteria.

The amount of pyrolusite mined annually throughout the world is over 1,300,000 tons. The principal producers are Russia, the United States, Greece, Brazil, and India.

When dressed to 95 per cent. MnO_2 (that is to say, nearly pure) it is worth about £3 per ton.

The black oxide of manganese was formerly much used in the manufacture of chlorine for bleaching powder, but electrolytic methods have now largely been adopted.

The blow-pipe reaction for manganese is distinctive. In the borax bead the colour is amethyst in the oxidising flame, the bead becomes colourless in the reducing flame, and the colour can be restored again by further heating in the oxidising flame.

Strongly heated in the closed tube, manganese dioxide gives off oxygen and would cause a smouldering splinter to glow more brightly.

When any manganese ore is fused with carbonate and nitrate of soda a green mass is produced; this is characteristic of manganese. This green mass, if dissolved in water and treated with lead dioxide and nitric acid, will yield a purple solution.

While pyrolusite is the principal ore, there are, in addition to the two other oxides mentioned above, a silicate, termed rhodonite, flesh-red in colour, and a carbonate termed rhodochrosite or dialogite. Neither of them occur in appreciable quantities.

MERCURY.

Mercury.—This is the only metal which is fluid at ordinary temperatures. It is found native to some extent, but more frequently as the sulphide, cinnabar, which when pure contains 86 per cent. of mercury.

Metallic mercury is occasionally found as small globules disseminated through earthy gangue, generally a clay shale.

Its gravity is about 13·5. It dissolves in nitric acid with evolution of brown fumes.

Native amalgam would be easily recognised by the sublimate of mercury given off on heating in the closed tube, and the residue would yield a button of silver when heated on charcoal before the blow-pipe.

Cinnabar, or sulphide of mercury, is found in Spain, United States, Russia, Austria, Italy, and Mexico. Small quantities of native amalgam (silver) have been found; they are very rare, but of very high value.

Cinnabar has already been described. Cinnabar, if quite pure, would entirely volatilise when heated on a shovel. That is to say, the mercury would all sublime, and nothing would be left but an incrustation of iron sulphide produced by some of the iron of the shovel combining with the sulphur out of the ore. It is usually found in sandstone, limestone, or shale formations. It is not easily dressed in the ordinary way with the aid of water, as it has a great tendency to slime. It is therefore commonly hammer-dressed and distilled in retorts with either

free lime or metallic iron (to combine with the sulphur), or it is distilled in large kiln-shaped furnaces through which air is passed and the vapours condensed in large chambers.

The annual production of mercury is from 3,000 to 4,000 metric tons, and is put up in bottles of 75 lbs., and the metal is worth about 2s. a pound.

The principal use of the metal is for the extraction of gold from its ores (*see* "The Metallurgy of Gold" in the Appendix).

Mercury is also of the highest value in the construction of barometers, thermometers, and pressure gauges. Its salts are employed in the arts and in medicine.

The estimation of mercury in cinnabar or ores containing same may be carried out as follows:—

From ·2 to 2 grams of the ore are mixed with zinc oxide, iron filings, or iron scale, and placed in a small Berlin porcelain crucible. A *pure* gold (or silver) cup (which fits well over the top of the crucible) is placed in position, having been previously weighed. The whole is heated at a gentle temperature by a bunsen or spirit-lamp for about 10 minutes or a quarter of an hour; the cup being filled with cold water, which is replaced every two or three minutes by more *cold* water by means of a pipette. The cup is removed, dried carefully, and weighed. The gain is mercury, from which the percentage in the ore is easily calculated. By simply heating the cup is freed from mercury, and is ready for the next assay.

Mercury ores are only found in few places in the world, and any fresh discoveries would be deserving of the most careful attention. It is not quite certain what is the lowest grade that would pay to work, and it would of course depend somewhat on local conditions, but as there is a steady demand for the metal, and the price is well maintained, even low grade ores would be of value in very inaccessible situations, where ores of the commoner metals could not pay to work.

MOLYBDENUM.

Molybdenum.—The chief ore of molybdenum is molybdenite, the sulphide, which is described under "Minerals with Metallic Lustre."

Wulfenite, lead molybdate, a yellow mineral, is also found, but in small quantities, and molybdic ochre, usually occurring as an incrustation, is also found native.

Molybdenite is employed in the manufacture of molybdenum steel, and certain pigments.

The compound of molybdic acid with ammonia is valued in the laboratory as a convenient reagent for the estimation of phosphates.

Molybdenite is mined, chiefly to a small extent, in New South Wales, in California, and Norway, the ore from the former locality being the purest.

The present value of molybdenite is about 1s. a pound for a fairly pure ore.* Low grades are of but little value, as they cannot be easily concentrated by the ordinary methods of dressing. The oil-concentration process, also magnetic separation, have been used successfully.

When molybdenite is roasted with free access of air, sulphurous acid gas is given off, and the trioxide (after long roasting at a moderate temperature) is left as a greyish powder. If the roasting is carried out at a very high temperature, the trioxide (molybdic acid) is volatilised. Molybdic acid prepared in the dry way as described is not so readily soluble in ammonia as when prepared by a wet method, but it does dissolve on continued warming.

Molybdenite may be assayed thus; digest in nitric acid with potassium chlorate, the mineral being first reduced to a powder.† The digestion takes a long time, when it is complete add excess of ammonia and boil. Filter and re-precipitate iron, and add filtrate to main bulk. To the boiling filtrate add acetic acid in slight excess, and precipitate with slight excess of lead acetate. Boil, filter, and extract several times with a boiling solution of ammonium acetate. Finally wash precipitate all on paper, dry, detach, precipitate, and ignite separately; then carefully ignite whole and weigh as lead molybdate, which contains 26·15 per cent. molybdenum.

Molybdenite in appearance is much like graphite, but is easily distinguished by the tests given in the monograph, the simplest of which is the evolution of sulphurous acid on roasting, which may be performed on a shovel.

NICKEL.

Nickel.—Nickel does not occur native, but is produced largely by smelting the sulphide ore, in which state it occurs most frequently, and often with a notable percentage of copper, to a matte containing these and other metals, and then refining this matte by various processes.

The metal can be deposited electrically on iron, copper, and certain alloys, and forms a coherent coating which resists

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* It must be about 90 per cent. molybdenum sulphide to be saleable. It is very difficult to dress.

† This is difficult on account of its scaly nature. It *must*, however, be ground to pass an 80 mesh, or the digestion in acid will take a long time. The best way to reduce it to a fine powder is to cut it up with scissors before grinding.

oxidation and takes a high polish. The alloy with steel is both hard and tenacious. "Nickel silver" or "German silver" is a mixture of nickel, copper, and zinc, often containing small additions of lead and tin. It is used to make spoons and forks and similar articles; nickel is largely used as an alloy for steel.

One of the most important modern uses of nickel is to form the outer skin of rifle bullets. With modern rifles the rapidity of the bullet through the barrel is so great that a soft (lead) bullet would tend to strip and foul the rifling, and hence modern rifle bullets consist of a coating of nickel filled with lead.

The principal ore of nickel mined at the present time is garnierite* (also called noumeite†).

Garnierite (which has already been described under "Green Minerals") may also be greyish or nearly white, and sometimes a brown; to this variety the name "chocolite" has been given.

Garnierite is mined in New Caledonia; it is essentially a silicate of nickel with magnesium silicate.

The ore from Sudbury is chiefly a nickel-iron-sulphide (Pentlandite) associated with a small quantity of chalcopyrite and a large amount of pyrrhotite.

Chloanthite, or "white nickel," is a silvery-white mineral, with metallic lustre, the streak is grey. It usually contains cobalt, and some varieties graduate into cobalt ores, inasmuch as they contain more cobalt than nickel.

Annabergite, or nickel bloom, is a light green amorphous incrustation found on chromite that has been exposed.

Morenosite occurs as an efflorescence, as needle-shaped crystals, of a pale-green colour.

Pimelite is a name given to a greenish clay, which contains nickel carbonate.

Zaratite is a green nickel carbonate.

In testing minerals for nickel, unless they appear to be fairly pure, it would be better to separate the nickel as hydrate by wet methods, as the presence of iron, copper, or cobalt would make the blow-pipe reactions unreliable. The following general method might be employed:—

A *qualitative* test for nickel may be applied by dissolving ore in nitric acid, baking to dryness, and boiling with hydrochloric acid. Dilute, boil, pass sulphuretted hydrogen till precipitation of copper, etc., is complete. Filter; oxidise filtrate with nitric acid. Nearly neutralise with soda, and add sodium acetate. Warm, and just boil. Filter, add ammonia to filtrate. A blue colouration will indicate *nickel*.

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* From the discoverer, Dr. Garnier.

† From the place, Noumea, New Caledonia.

Fresh discoveries of nickel would be of no commercial importance, unless they were of a size and quality to enable them to compete with the large deposits in Canada and New Caledonia. Small deposits, unless exceptionally rich, would scarcely be worth much expenditure.

NITROGEN.

Nitrogen.—This element in gaseous form constitutes about 79 parts by volume, or about 77 parts by weight of the earth's atmosphere.

Its mineral compounds are few, the deposits of nitrate of soda and nitrate of potassium being the most important. In the form of ammonia it is an important constituent of guano. (*See* under "Brown Minerals.")

Nitrogen is essential to the growth of all vegetable and animal life. Some plants, in particular the leguminosæ (the peas, beans, vetches, etc.) have the power, with the aid of certain bacteria, of extracting the gaseous nitrogen from the air and fixing it in their structure, but these as well as all other plants are greatly benefitted by being manured with a substance containing nitrogen, and nitrogen in the form of a nitrate is most readily assimilated.

When plants are eaten by animals, a part of their nitrogen is voided in the fæces and urine, and a part is retained and enters into the composition of their flesh, blood, hair, skin and bone. Every animal, therefore, that is grown on a certain piece of land takes from it a certain quantity of combined nitrogen. In the same way all crops that are removed from a certain piece of land also remove a certain quantity of combined nitrogen. Unless this nitrogen is put back on the land, in the form of ammonia, nitrogenous manure, etc., the land will become poorer in nitrogen unless care is taken to grow from time to time such crops as the leguminosæ above mentioned. Just in the same way the other two essential ingredients of fertile soil, potash and phosphorus, are also removed, and they must be restored either naturally or artificially if the fertility of the soil is to be maintained.

When decomposing animal matter comes in contact with an alkali such as the carbonates of calcium, potassium or sodium, the nitrate of these metals is produced, owing to the action of a class of bacteria termed the "nitrifying" bacteria.* The deposits of nitrate of potash found in India and the nitrate of soda found in Chili are believed to have their origin in this manner. Any further deposits of these minerals would be of high commercial value. Being soluble in water they would

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* *See* "Applied Bacteriology." (Pearmain and Moor.)

only be found in countries where the rainfall is very small. They would be very easily identified owing to (1) their solubility in water; (2) their deflagration on igniting on charcoal. The flame colouration will at once distinguish between potassium and sodium.

The amount of sodium nitrate annually mined is over $1\frac{1}{2}$ million tons and it is worth about £10 10s. per ton.

The amount of potassium nitrate mined in India is about 20,000 tons, and it is worth about £15 per ton.

A good deal of potassium nitrate is made by mixing solutions of sodium nitrate and potassium sulphate. The resulting potassium nitrate is separated by fractional crystallisation.

Nitrate of potash was formerly made in many European countries by exposing heaps of decomposing organic matter and mineral matter containing calcium carbonate and wood-ashes to the action of air and moisture. (It is still made in India in this way.) Periodically portions of the heap are lixiviated and the solution evaporated and re-crystallised.

Guano is the more or less fossilised dung of sea-birds, containing also the bones of birds and of fish. Methods for its recognition will be found under "Brown Minerals."

Guano contains nitrogen in the form of ammonia, usually oxalate, carbonate and phosphate. It is sold on the basis of the ammonia and phosphoric acid it contains, and varies in price from £3 to £5 per ton. Many of the known deposits of guano are partly exhausted, and any further discoveries, if of fair extent, of good quality and reasonable accessibility, would be of great value. Guano used to be used as a source of the ammonia salts of commerce. Ammonia is now entirely prepared from the destructive distillation of coal, shale, etc.

Native sulphate of ammonia (mascagnite) has been found in the neighbourhood of volcanoes.

Whether it has ever been found in sufficient amount to work is questionable, but it might be. The sulphate of ammonia of the gas works is worth about £12 a ton. Native ammonium chloride has also been found as an incrustation about volcanoes.

A compound of nitrogen with carbon (namely, cyanogen) is of such great importance in metallurgical work that, although it does not occur native, it is not out of place to refer to it here.

The compound that is most employed is the combination with the alkali metals, namely, the cyanide of potassium and the cyanide of sodium.

These salts are used in assay work as reducing agents, they melt without decomposition at a dull red heat, and at a white heat are slightly volatilised. When melted with certain oxides (like copper oxide, tin oxide, etc.) they not only reduce the oxides

to the metallic state, by combining with the oxygen, but also protect the reduced metal from being re-oxidised by the air.

The cyanides of the alkali metals are very largely employed to dissolve out the finely divided particles of gold left in quartz and in pyrites* after all that can be removed by amalgamation has already been extracted.

Cyanide of potassium and of sodium are made principally from the crude solution of sulpho-cyanide of ammonium which is produced at gasworks. It is also made by the decomposition of the corresponding ferro-salts.

PHOSPHORUS.

Phosphorus.—Guano, the fossilised excreta and remains of sea-birds, has already been referred to under "Nitrogen," and the methods for its identification have been given under "Brown Minerals."

Phosphorus also occurs in several minerals in combination with calcium as apatite, phosphatic rock, earthy apatite (or osteolite), coprolites, bone-beds, mussel-mud, etc. All sea-shells and coral contain a certain proportion of phosphates. The ash of every portion of every animal and vegetable structure contains combined phosphorus; in fact, no life is possible without it.

Phosphorus is still employed to a large extent in the manufacture of matches, though not so much as formerly, as the "safety matches" do not contain phosphorus, but are a mixture of potassium chlorate, sulphur, etc., and the composition on the box contains a little red phosphorus. (Some safety matches will strike on a piece of charcoal.)

Phosphorus has a limited use in metallurgy. It is alloyed with tin to form "phosphor-tin," which is again used in the manufacture of "phosphor-bronze," consisting of about 82 per cent. copper, 13 per cent. tin, 4 per cent. lead, and about ½ per cent. phosphorus. It is used in marine engineering to a small extent.

Phosphatic rock, coprolites, and osteolite are mined or dredged, and then ground up for fertilisers. They are either employed without any further treatment beyond grinding, or are converted into super-phosphate or "soluble phosphate" by treatment in fine powder with sulphuric acid.

In the steel from phosphoric pig irons, lime is used to combine with the phosphorus, the phosphorus is recovered as a slag containing phosphate of calcium, together with uncombined lime and other oxides; it is known as "Basic slag," and, when

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* See "The Metallurgy of Gold" in the Appendix.

finely ground, is employed as a cheap phosphatic fertiliser. It is especially valuable as an application for lands requiring both phosphates and free lime, such as poor clay lands or poor lands containing much vegetable matter or acid from the growth of peaty matter.

Discoveries of phosphatic rock may be of great importance, if of good extent and fairly free from impurities. Such deposits occur on a large scale in North Carolina, Florida, Egypt, etc., and there is no doubt that many others will be discovered. The methods for the identification of phosphatic rock have been described under "Brown Minerals."

As the value of a deposit of phosphatic rock depends principally on its percentage of phosphoric acid, a method for its assay will be useful. A method suitable for the determination of phosphoric acid in phosphatic rock, osteolite, coprolite, "Basic slag," guano, etc., is the following:—

Take about 1 lb. of the sample, which must have been carefully sampled from bulk,[*] grind until all passes a 30 mesh, and take about 1 oz. and grind finely. Then weigh out 20 grammes and dissolve in dilute warm nitric acid. Note whether there is any effervescence.

If a sediment or undissolved portion remains, dilute the solution and filter.

Make the filtrate up with washing to 1,000 c.c. and take 50 c.c.[†] Make alkaline with ammonia till opalescent, add 2 c.c. of strong nitric acid and heat to 70° Centigrade, add 20 cc. of a 10 per cent. solution of ammonium molybdate and stir, keeping hot, for 10 minutes.

Ammonio-molybdenum phosphate will separate as a canary-coloured powder.

Filter, wash and dry. The weight multiplied by ·0373 gives the phosphate present as P_2O_5.

The world's production of phosphatic rock is about 4,000,000 tons annually.

PLATINUM.

Platinum.—Platinum almost always occurs native[‡]; it has not yet been found in rock in payable quantities. It is frequently associated with gold. Native platinum is usually impure, and contains equally, in addition to iron, some of the other metals of the platinum group, such as iridium, osmium, rhodium, etc.

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[*] See article on "Sampling."

[†] This is equivalent to 1 gram of original sample.

[‡] The only exception to this is the rare compound known as *sperrylite*, or arsenide of platinum, which is very rare. It has been found with the copper-nickel ores of Ontario.

It is found in Siberia, and to a small extent in Borneo, Colombia, Australia, New Zealand, and Canada.

Platinum is found in small nuggets or grains of a greyish silver or lead colour. They are malleable, or only slightly so, according to the purity of the metal. Native platinum is rarely hard, and can usually be extended under the hammer without breaking. The streak (on a file or on a rough stone) is the same as the metal. Platinum is unaltered in colour and infusible before the ordinary blow-pipe and in the highest heat of the wind furnace, but melts in the oxy-hydrogen flame. It forms an alloy with lead, and can be cupelled like gold and silver, but the temperature required for the complete oxidation of the lead is a good deal higher than is the case with gold or silver. When a gold bead (after cupelling) contains platinum, the surface of it will be frosted instead of being quite smooth and bright.

Platinum is unaffected by sulphuric acid and by hydrochloric or nitric acid applied separately.

It dissolves in nitro-hydrochloric acid (aqua-regia). The solution of chloride of platinum is yellow. On the addition of potassium chloride, a double potassio-platinic chloride is precipitated in yellow scales. This reaction is taken advantage of in the estimation of potassium. On account of its infusibility it is employed by chemists in the form of crucibles, dishes, wire, &c., and its chemical compounds are used in photography. Perhaps its most important application is its use in the construction of incandescent electric lamps.

It is used in these to join the wires carrying the filament to the wires outside the bulb. As platinum expands and contracts at the same rate as glass does, it is specially adapted for this purpose, as if any metal having a less or greater expansion and contraction than glass were employed the glass would be liable to fracture.

A fraction of a pennyworth of platinum wire is used in each lamp. Some of these lamps are saved and the platinum is recovered, but many are destroyed or thrown away.

The present production of platinum is from 9 to 10 tons a year. Crude platinum is purchased by platinum refiners at prices varying according to its impurities, the metal is manufactured into the shape of foil, sheet, basins, or wire.

Any new discoveries of platinum would be of great importance, and a quantity of a few grains to the cubic yard would pay to work, if water could be brought on for hydraulicking.

Iridium and Osmiridium.—Iridium has been used for the points of certain kinds of pen-nibs, and is largely used as an iridio-platinum alloy in various forms of thermo-electric pyrometers.

Osmium is used in the form of osmic acid in physiological research, and has also been employed in electric-lamp making.

Iridium and osmiridium are found in Russia, Colombia, Australia, and New Zealand.

Iridium and osmiridium are always found in alluvial deposits and usually associated with gold.

POTASSIUM.

Potassium.—Potassium is a silvery-white metal, which oxidises rapidly in the air and decomposes water with so great an evolution of heat that the hydrogen which is liberated takes fire. It is hardly necessary to say that it is never found in the metallic state, but its salts are distributed everywhere, and are essential to all vegetable growth.

The ashes of all plants contain potash in varying quantities, and wood ashes were formerly the principal source of the potash and potassium salts of commerce.

The chief commercial source of potash salts are the Stassfurt beds in Germany, though a certain amount of potash is still derived from wood ashes.[*]

Potash is contained in several minerals, notably certain felspars, in an insoluble form, and many attempts have been made to extract it, but they have not been commercially successful, and are not likely to be so while mineral deposits of soluble salts hold out.

The chief salts of potash found native are the nitrate, the chloride and the sulphate.

Potassium nitrate.—This salt is found as an efflorescence on, or an impregnation in the soil in certain parts of India, Spain, Egypt, and America.

It is purified by solution and recrystallisation. It is white or greyish according to its purity.

It deflagrates when heated with charcoal. Heated alone it fuses, unchanged, but imparts a lilac colour to a flame. This colour is difficult to see if soda is present. Potassium nitrate crystallises in right rhombic prisms.

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[*] Potash or pearlash is made by soaking wood ashes in water and boiling down the solution. The crude potash is ignited to burn off impurities and is dissolved in a certain amount of water and boiled with milk of lime. This removes carbonic acid and some sulphuric acid. The clear liquor is syphoned off and evaporated. The pearlash then contains over 60 per cent. of potash with other potash salts. There are several British Possessions where potash burning would pay, the chief desiderata being, plenty of wood, cheap labour, and means of transport.

Carnallite.—This salt is found in large quantities in the well-known Stassfurt beds. It is a double chloride of potassium and magnesium.

If pure, it is white, but may be reddish, owing to iron oxide. It is soluble in water, and gives reactions for potassium, chlorides, and magnesium.

Kainit.—An impure potassium sulphate, this mineral is also found in the Stassfurt beds. It is used for the preparation of fertilisers and also as a source of other potash salts, which are obtained from it by a similar process to that employed in making carbonate of soda from "salt-cake" (sodium sulphate).

Other sources of potash salts are the liquors obtained from the lixiviation of the ashes of seaweeds and from the ashes of "vinasse," the refuse left after making beet-sugar.

Any discoveries of potash salts would be of importance and deserving of a careful examination and testing.

Nitrate of potash is worth about £15 a ton. Kainit is sold on the percentage of potash it contains, and is generally worth about £4 a ton.

SILICON.

Silicon (and Silicates).—Silica (the oxide of silicon), in various forms and combinations, is very widely distributed; and in combination with calcium, aluminium, magnesium and iron as silicates, forms a principal constituent of most ordinary rocks.

Quartz and flint, ordinary sand and sandstone, consist almost entirely of silica; it is the chief constituent of all "acid" rocks. The word "acid" is used to distinguish this class of rocks from "basic" rocks such as limestone and dolomite.

The compounds of metals with silica found in nature are comparatively few and unimportant. Thus the noble metals form no compounds at all with silica, nor do tin, lead, bismuth, mercury, arsenic, antimony, chromium, and several others, but such silicates as those of copper, zinc, iron, nickel, manganese, are found and some of them are of commercial value.

Silica is insoluble in water* and in all acids except hydrofluoric. Silica which is artificially prepared in a very fine state of division, such for example as by acting on clay (aluminium silicate with sulphuric acid), is soluble in a boiling solution of potassium carbonate, whereas natural silica is not, or only very slightly so. Some of the silicates are decomposed by hydrochloric acid, the silica remaining either as an insoluble *powder* or in a gelatinous condition. If it is in a gelatinous condition it changes into the powdery form on heating to dryness.

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* Silica is not *entirely* insoluble in water, as it enters into the composition of many plants—for example, the stalks of cereals and other plants.

Fused silica is now made into flasks, tubes, dishes, &c., and is likely to prove very useful in chemical work.

Silica dissolves in melted borax, producing a colourless transparent bead; in a microcosmic salt bead it does not dissolve, but floats about as a partly transparent skeleton.

Fused with carbonate of soda, reaction takes place, sodium silicate being formed and carbonic acid being given off with effervescence. It is this gas which causes the bubbling and boiling in the case of many fire-assays (such as the assay of gold ores, in which carbonate of soda is added to make the silica and silicates form compounds that are fusible at convenient temperatures).

A large group of silicates, namely, clays, tourmaline, mica, talc, felspars and many others, are insoluble in hydrochloric, but can be decomposed by hydrofluoric acid or by fusing with "fusion mixture," a mixture of sodium and potassium carbonates.

Agate, a very compact variety of quartz, is of use on account of its hardness. It is used in the construction of balances and for mortars for fine grinding. Its hardness is about 8·0.

SILVER.

Silver.—This metal is found native, but not usually in large quantities.

Silver is found in varying quantities in galena (sulphide of lead) all over the world. All galena contains some silver; the amount varies from less than an ounce per ton up to thousands of ounces.

The chief ores of silver are the sulphide, argentite, the chloride known as "horn-silver" or cerargyrite, stephanite, proustite, pyrargyrite. Iodide of silver and bromide of silver are also sometimes found.

Small quantities of silver (and gold) are also frequently found in both iron and copper pyrites.

The silver minerals may be more or less easily converted into the metal before the blowpipe when ignited with sodium carbonate.

Native silver gives a shining silvery streak and fuses before the blowpipe, yielding a white malleable bead, and may give a dark red incrustation on the charcoal.

Argentite, or sulphide of silver, is greyish-black with metallic lustre, and on ignition alone before the blowpipe yields a bead of silver, fumes of sulphurous acid gas being evolved.

The mineral is sectile. Its specific gravity is high, being about 7·2.

Horn-silver, when pure, has a greyish-white colour and is of the consistence of horn, and can be cut with a knife.

If a stone is believed to contain horn-silver, cerargyrite, it may be powdered and rubbed with water on a piece of bright copper, which will be covered with a coating of metallic silver if either horn-silver, or silver bromide, or iodine is present. Horn-silver is soluble in ammonia, but not in acids.

Stephanite, or brittle silver ore, is iron-black in colour; it is a double sulphide of silver and antimony. Ignited before the blowpipe it yields a black globule and a whitish incrustation of antimony. If the black bead of silver and antimony is reheated with carbonate of soda, a bead of silver is obtained.

Pyrargyrite, "dark-red silver ore," is also a double sulphide of silver and antimony; it is usually dark red in colour. It behaves in a similar manner to stephanite before the blowpipe. In colour it may vary from nearly black to a bright-red colour.

Proustite, "light red silver ore," is bright-red in colour, more or less translucent, and consists of a double sulphide of silver and arsenic. Heated alone before the blowpipe, fumes of arsenious oxide and of sulphurous acid gas are given off, and with carbonate of soda a bead of silver is produced. Both pyrargyrite and proustite are sometimes called "ruby silver ore."

Stromeyerite consists of the mixed sulphides of silver and copper; colour, steel grey, the streak is the same as the colour; gives reactions for sulphur and copper, and on cupelling, a bead of silver. This ore sometimes contains from 50 to 60 per cent. silver.

All silver ores may be assayed by smelting with metallic lead or litharge and fusion mixture, a similar procedure being followed to that described under "Gold." The resulting button of lead will contain the silver and is then cupelled. It is now possible to obtain assay lead, litharge and red lead all practically free from silver, and it must also be recollected that to obtain *accurate* results from an assay of any ore containing silver it is necessary that the lead button obtained on fusion should be of a certain weight, or there is a danger of silver remaining in the slag. That, however, is not a matter of great consequence for the purposes of prospecting.

Most silver ores or ores containing silver may carry varying amounts of gold, which will, of course, be in the silver bead obtained on cupelling.

The world's annual production is about 200,000,000 ounces.

SODIUM.

Sodium.—This metal, like potassium, oxidises rapidly in the air, and decomposes in water, and therefore is never found native. Its salts, particularly the chloride, are widely distributed. Sea water contains on the average 3–4 per cent. of salts, of which about 90 per cent. is sodium chloride. Large beds of rock-salt also occur in England, on the Continent, and in America, India, China and elsewhere.

Sometimes the salt is quarried or mined in the solid state, as rock-salt;* in other cases it is dissolved by pumping water into the mines, and pumping out the brine solution which is then evaporated and crystallised.

It crystallises in cubes, with a vitreous lustre. It would usually be recognised at once by taste. The colour imparted to a flame by a very small amount is intensely yellow.

Enormous quantities are employed with food all over the world, and very large quantities are employed in the manufacture of carbonate of soda, caustic soda, etc.

The production of metallic sodium is about 4,000 tons a year.

Sodium is made by Castner's process, viz.:—The electrolysis of molten caustic soda in suitable vessels. It is used for reducing other metals and making sodium peroxide.

Nitrate of soda†, also known as Chili saltpetre, is found as an efflorescence and as an incrusted salt in very large quantities in Chili and Peru. When pure it is white and crystallises in rhombohedrons. It is readily soluble in water. Heated alone it melts, heated on charcoal it deflagrates with a bright yellow flame. It is deliquescent (that is to say, absorbs moisture) and becomes wet. Potassium nitrate is not deliquescent. The flame test is sufficient to distinguish these salts.

Sulphate of soda, also known as *Glauber's salt* and "mirabilite," is found native. It effloresces in air; that is to say, parts with its water of crystallisation and falls to a white powder.

Carbonates of soda, known as natron and trona, are also found native. They would be recognised by effervescing readily with all acids and colouring a flame intensely yellow.

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* See "Halite" under "White Minerals."

† See under "Nitrogen."

STRONTIUM.

Strontium.—This metal like calcium oxidises rapidly when exposed to the air, and is consequently never found native. The metal has no commercial applications, and can only be prepared electrolytically in small quantities and is a scientific curiosity.

The principal minerals containing it are the sulphate, celestine, and the carbonate, strontianite. Both of these are found in various parts of the British Isles, in Europe, and in other parts of the world.

Celestine, if pure, would be white, but is usually of a faint bluish tint; strontianite is generally whitish, dirty white or yellowish. They are both rather heavy, celestine having a specific gravity of about 3·9, strontianite being about 3·7.

When moistened with hydrochloric acid celestine is unaffected, strontianite is dissolved with evolution of carbonic acid. They afford a red flame colouration, more vivid than that of calcium compounds, but not so bright as that given by lithia salts.

Celestine melts before the blowpipe, and if ignited with charcoal is partially reduced to the sulphide, which placed on a bright silver coin and moistened with a drop of water gives a brownish stain, affording evidence of the presence of sulphur.

Strontianite swells up before the blowpipe and is partially converted into the oxide, which is alkaline, and when moistened renders red litmus paper blue.

The chief commercial salt of strontium is the nitrate, which is used to produce red fire in pyrotechny.

SULPHUR.

Sulphur.—Sulphur is found native, chiefly in the neighbourhood of volcanoes. It is usually mixed with earth and stones, and is purified by sublimation, or liquation.

It exists also in direct combination as sulphide of several metals, such as iron, copper, lead, silver, bismuth, arsenic, etc.

Where the compound is not itself volatile the sulphur, or a part of it, may be obtained by simple heating.

Sulphur occurs as sulphates, such as sulphate of calcium, aluminium, and magnesium and (in very much smaller quantities) as the sulphate of iron, zinc, copper, and lead.

Sulphate of calcium (or gypsum) is found in very large quantities.

None of the native sulphides are soluble in water, the sulphides of the metals are some of them soluble in hydrochloric acid, but all are decomposed by nitric acid or aqua-regia, with or without separation of sulphur.

Free sulphur is at once recognised by its ready burning in presence of air, and the production of sulphurous acid gas. If present as a sulphide, the smell of sulphurous acid gas is noticed on heating in presence of air, and if present as a sulphate, it may be recognised, if the salt is soluble, by its giving a heavy white precipitate with a soluble barium salt.

If the sulphate is insoluble it must be fused with sodium carbonate, and the resulting mass dissolved in water before testing with hydrochloric acid and filtering. There is also a convenient dry test which consists in fusing the material to be tested with carbonate of soda on charcoal. The mass obtained is then powdered and placed with a little water on a clean silver coin, when a brownish black stain will appear if a sulphate was present, owing to its having been partially reduced by the action of the charcoal.

TANTALUM.

Tantalum.—The chief ore of this rare metal is the mangano-tantalate of Western Australia.

This ore contains from 60 to 70 per cent. of tantalic acid (Ta_2O_5) and some niobate (columbate).*

Samaskhite, or urano-tantalite, is a rare mineral found in Carolina, it contains in addition other rare earths.

A tantalate of antimony has been found in Australia, and ferro-tantalate is found in America. The American ores often contain more niobium than tantalum, and are termed columbites.

The commercial value of tantalite depends largely on its consisting mainly of tantalic acid, not niobic.

An alloy of steel with tantalum exhibits remarkable hardness and tensile strength, and the metal tantalum is so hard that it has been hoped it may be useful in rock-drilling.

In appearance tantalite is similar to some samples of cassiterite and of wolfram, but is readily distinguished from the latter by boiling in aquaregia and from cassiterite by the blowpipe.

Tantalite does not dissolve in any acid except hydrofluoric in which it dissolves in the cold, if finely powdered.

The mineral can be opened up by fusion with caustic potash or potassium carbonate, and the addition of hydrofluoric acid to the aqueous solution of the fused mineral throws down potassium fluo-tantalate. This salt is insoluble, or nearly so, in water, whereas the corresponding niobium compound is much more soluble. The reaction, therefore, affords a means of distinc-

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* Columbium is another name for niobium, and some American ores are known as columbite.

tion from "columbite" containing little or no tantalum,* and the quantitative estimation is based upon this fact.

The chief mineral containing this element is tantalite, containing 70 per cent. of tantalic oxide. It occurs also in smaller quantities in niobite, and occasionally with tin ores. The metal has only recently been prepared in a pure state. It somewhat resembles platinum in appearance, and is found to be extremely ductile. It is used in the form of very fine wire in the incandescent electric lamps *in vacuo* as a substitute for a carbon filament, the saving of current being considerable. It forms with carbon an extremely hard material, and it has been suggested trying it as a substitute for diamond in drilling. The metal is oxidised before the blowpipe to a white powder (the oxide above mentioned). Tantalite is a heavy black mineral of sp. gr. about 7·0, with a brownish-olive streak. It is almost insoluble in all acids, but can be got into solution by fusion with caustic potash. All acids and ammonia produce a white precipitate. On the addition of hydrofluoric acid a white crystallised precipitate is produced, and is used as a means of distinction from niobite (columbite), which it greatly resembles.

TELLURIUM.

Tellurium.—This metal is found alone and in company with gold, silver, and mercury.

Tellurium has at present no commercial use, but its presence might probably indicate the neighbourhood of tellurides containing gold and silver.

The various species of tellurides and their general characters have been already described under "Minerals with Metallic Lustre."

A distinctive feature of tellurium and all tellurides is the formation of a white sublimate (melting into colourless drops on heating) when anything containing tellurium is ignited in an open tube.

Heated on charcoal, tellurides yield a whitish sublimate, something like that obtained from antimony compounds.

In the case of tellurides rich in gold or silver a bead of these metals might be obtained after prolonged heating on charcoal.

The following tests are convenient for the recognition of tellurides.

A small quantity of the mineral is finely powdered and heated with strong sulphuric acid. The acid will turn a bright violet colour; cool and pour the acid into a white dish and add water; the liquid will lose its violet colour and become turbid, a dark precipitate of tellurium being formed.

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* "Tantalum," a paper by F. H. and W. A. Michell (Redruth), 1906.

If sulphuric acid is not at hand the test may be varied by heating the mineral (in fine powder) with some sodium carbonate and charcoal powder, in a tube or crucible. After cooling the powder is stirred in a dish with water, and when the powder has settled, the water will be seen to have a violet tinge, which gradually fades on exposure to air.

Mr. S. J. Lett informs the author that the test originally proposed by Kustel answers well with gold ores containing tellurium. The powdered ore is placed in a dish with water and mercury and sodium amalgam. The water is poured off and fresh sodium amalgam added. A violet colour is produced if tellurium is present.

Estimation of gold and silver contained in telluride ores:—

As tellurium is volatile, there is danger of the precious metals being partly volatilised if assayed by the ordinary fusion methods. If, however, a larger quantity of lead (or litharge) is employed, this danger is minimised. If an extra quantity of litharge is used, a little sand should be added to protect the crucible, as a slow fusion is advisable in some telluride ores. The cupel should be carefully examined, as tellurium sometimes causes the gold bead to split up into small particles on the cupel.

The tellurides may be found massive, but if distributed in gangue, the mineral should first be concentrated by panning.

The ores have a great tendency to slime, and their treatment presents difficulty.

On account of their high value, any discovery is deserving of the most careful consideration, and every mineral supposed to contain tellurium should be assayed for gold and silver, using double the quantity of litharge ordinarily employed.

THORIUM.

Thorium and other metals of the rare earths.—Minerals containing thorium in workable quantities are of value for the manufacture of the incandescent mantles now so largely employed in gas lighting. The principal mineral used for the preparation of thorium is monazite (which is described under "Brown Minerals"). It is essentially phosphate of cerium and lanthanum with thorium silicate.

To be of commercial value for the preparation of thorium salts it must contain at least 2½ per cent. of thoria, monazite appears to vary from 2 to 13 per cent. of thoria.

Cerium is employed to a very small extent in medicine; small quantities are also used in the manufacture of incandescent mantles for gas lamps.

Monazite sand is often accompanied by titaniferous iron sand, or magnetite. Monazite is itself capable of being separated from non-magnetic gangue by the application of a suitable current with an electro-magnetic separator.

The identification of monazite has been described, the fact that it affords the test for phosphates and has a notably higher specific gravity than ordinary sand being the two most salient characters.

Monazite is at present obtained from Brazil, North Carolina, Virginia, and (to a less extent) from Ceylon. It occurs also in Russia.

Another mineral containing thorium is thorite,* a mineral consisting essentially of thorium silicate; it is usually black, but a reddish yellow variety is found, termed "orangite."

Thorianite, an impure oxide of thorium, has been found in small quantities in Ceylon. It contains uranium and traces of other metals.

The separation of the metals of the rare earths as a group can be effected in the case of monazite sand, fergusonite and certain other rare minerals, as follows:—

As monazite is not attracted by the hand magnet, any particles that adhere to a magnet may first be removed, and anything soluble in hydrochloric or nitric acid may also be removed.

Grind first to the finest possible powder, and then either fuse 3 grams with 9 grams potassium bisulphate, or digest 3 grams hot with 10 c.c. strong sulphuric acid, and evaporate until fumes of acid cease to come off. If sulphuric acid is used it is advisable to evaporate twice with 10 c.c. of acid each time in this manner, so as to ensure complete decomposition. The fusion or digestion may be carried out in a platinum dish.

After the fused or digested substance has been cooled it is treated with cold water, which will remove the earths together with alumina and some lime (if present). The bases will be in combination mostly as sulphates and phosphates. The digestion with cold water should be done with successive quantities of 5 c.c., breaking up the fused or digested substance with a glass rod so as to bring every particle into contact with the water. Not more that 30 c.c. of water should be used in all, the aqueous extract being passed through a small filter. The solution is then precipitated with 2 grams of oxalic acid dissolved in 10 c.c. of water; this should be done in the cold.

This precipitate contains the rare earths as oxalates, together with some calcium, aluminium, and iron. The precipitate is washed off the filter with 30 c.c. of ½ per cent. hydrochloric

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* Described under "Black Minerals."

acid, the liquid removed as far as possible by decantation. It is then dissolved in strong nitric acid, and the earths are precipitated with ammonia. This precipitate is dissolved in hydrochloric acid, and any heavy metals that may be present are removed by passing sulphuretted hydrogen. The filtered liquid is boiled to expel sulphuretted hydrogen and the earths re-precipitated by ammonia.

They are then ignited, and consist of the oxides of the rare earths, namely, thorium, cerium, lanthanum, didymium, yttrium and erbium.

Thorium may be more or less completely separated from the mixture of the oxides of the other rare earths by adding sodium hyposulphite to a hydrochloric acid solution, when thorium sulphite is precipitated. This may be filtered off and ignited twice with nitric acid and weighed as thoria.

Gadolinite is essentially a silicate of yttrium, with silicate of glucinium. *Fergusonite* is essentially a columite of yttrium.

TIN.

Tin.—Tin is found* in Cornwall, Malay Peninsula, China, Saxony, Australia, and Bolivia.

Tin is nearly always found as the dioxide or cassiterite, commercially known as "black tin," though its colour when ground is really a dark brown. Its specific gravity is from 6–7.

It occurs in lode stuff and also as stream tin,† the latter being generally, but not always the purer. When stones rich in tin are examined they can often be recognised by their appearance, but if other minerals are present, or if the oxide of tin is very finely disseminated, it may not be recognisable until the stone is ground and panned or vanned.

It is recognised by the heaviness of the stones, and by the appearance in the pan on washing (after grinding). The "head" in the pan is generally a light or dark brown, and on drying and igniting with a little cyanide a bead of tin is obtained. This is soft, and can be cut with a knife and does not mark paper. Metallic tin is at present worth about £135 per ton.

Commercial "black tin" is worth at present from about £80 per ton according to percentage of tin and freedom from impurities.

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* See "The Tin Deposits of the World" by Sidney Fawns.

† As cassiterite, like gold and platinum, is totally insoluble in water, it is found in alluvial deposits which may be of considerable age.

Stream tin should be sought by panning gravel and sand in streams or alluvial deposits.

In lode-stuff tin sometimes occurs so rich that it does not require "dressing," though such deposits are very rare and are naturally exceedingly valuable.

When in lode stuff the average percentage that is payable in the United Kingdom may be taken as 1 to 2 per cent. if conditions are otherwise favourable.

The impurities common to tin ore are compounds of iron, arsenic, copper, lead, and wolfram. The latter possesses a specific gravity almost the same as cassiterite, and cannot be removed by dressing with water; it is now removed magnetically.

The "black tin" is reduced to metal by smelting in a reverberatory furnace with anthracite and suitable fluxes.

The chief application of tin is for the production of tin-plate. It is probable that the demand for tin will rather increase than diminish as time goes on.

It is also used in solder and certain alloys such as bronze, bell metal, pewter-pot metal, and Britannia metal; and its salts are employed in the textile industries.

Cassiterite is remarkable for the various colours it may possess. If it were quite pure it would be white, and the native oxide is sometimes found white and opaque, or greyish white, as for instance in parts of Bolivia, New South Wales, and Tasmania.

"Ruby" tin is also found of a ruby red colour, partly transparent.

The most common colour is brown or black. Sometimes the "black" tin has a distinct purple tint.

Cassiterite may also be brown and transparent (rosin tin) and yellowish and transparent.

In open workings where the overburden is slight and there are very large deposits of rock containing tin disseminated throughout the whole mass, it has been possible to carry on operations when the total recoverable quantity of "black tin" has averaged only 7 lbs. to the ton, or about ·3 per cent. This may be taken as about the lowest grade of ore that can be profitably worked.

In streaming operations on alluvial where crushing is not necessary, it is possible to work on as little as 1 lb. of black tin to the cubic yard, provided good water-pressure is available.

To assay tin ore, stream tin, commercial "black tin," mill-sand or slimes for tin, the best method to use is the cyanide

assay, and the same quantity, 5 grams, should be regularly employed, with three times the weight of potassium cyanide.

For a successful result it is necessary in the first place to remove all silica and silicates as completely as possible by mechanical means (*i.e.*, by vanning). The silica cannot be fluxed away (as, for example, in a copper assay), because silica combines with cassiterite at a red heat, forming a silicate, which cannot be completely decomposed again.

[This necessity of removing the silica and silicates and of producing a sufficient quantity of concentrate, which must (when acid-cleaned) be as near 5 grams as possible, means that a good deal of labour must be undertaken in vanning down low-grade ores, sands or slimes, and therefore many people content themselves by reporting the concentrate obtained on vanning an ounce, calling the result "black tin," and even in many cases without removing acid-soluble impurities. A common plan is to "burn" the concentrate at a dull red heat, and remove anything that will come up to a hand magnet. While fairly accurate results may often be obtained in this way, very great errors are often made, and large quantities of calybite have been passed as cassiterite, while wolfram, titanic acid, sphene, partly burnt sulphides, tourmaline, etc. may be weighed up as cassiterite.]

The material to be tested should be reduced first to a 30-mesh powder, and vanned in quantities of one ounce at a time, the concentrates being dried, weighed, and preserved, until about 6 grams of concentrate have been collected. [Care must be taken to regrind the tails after collecting each concentrate, if necessary.]

The collected concentrates are then treated with aqua-regia, and heated in a covered dish for half an hour.

[If wolfram is present, for six hours.]

If wolfram is not present, the acid liquor is removed by decantations and the concentrate replaced on the shovel.

It will then be found possible to van away a little more silica, which was previously attached to particles of cassiterite by iron compounds.

The cleaned concentrate is dried, weighed, and three times its weight of dry potassium cyanide weighed out. About 2 grams of cyanide are placed in the bottom of the crucible, which should be a pointed one, 4 inches high and 2 inches wide at the top. Five grams are also reserved for "cover." The rest of the cyanide is mixed with the concentrate by grinding quickly together in a porcelain mortar.

The crucible is charged, covered with the 5 grams of cyanide, and placed in the furnace, and quickly brought up to a

dull cherry red, at which it is kept for eight* minutes. It is then tapped two or three times to cause the reduced tin to unite into a button, and the melt quickly poured into a warm cast iron mould.

It might be said that the method of ignition in hydrogen would give equally good or even more correct results than the foregoing, but as this method gives the total tin present, entirely irrespectively of whether it can be mechanically concentrated or not, by the means ordinarily employed, it is evident that the foregoing method is preferable.

NOTE.—In assaying tin-slime, whether rich, poor, or very poor (*i.e.*, tailings from ragging frames) after weighing out the samples, roast and digest in acid *before* vanning. This removes a quantity of iron and enables the vanning to be more easily and accurately performed, the percentage is, of course, calculated on the original amount of material taken.

The anthracite method is sometimes used by smelters to determine the amount of tin likely to be obtained from the black tin purchased by them for smelting, and in skilled hands the process gives useful commercial results.

Eighty grams of the black tin without previous acid treatment are mixed with 16 grams of powdered anthracite, and by means of a scoop are charged into a red-hot graphite crucible. If the tin contains much impurity of other metals add a little fluorspar. The process of reduction takes from 20 to 30 minutes in a hot fire. The contents of the pot are poured into an iron mould, the slag being held back by means of a piece of stick placed just above the lip of the pot. The button is cleaned and weighed. The slag and scrapings from the pot are placed in a mortar, crushed to a coarse powder, and the flattened prills of tin separated from the slag by washing.

After drying the prills are weighed and the weight added to that of the large button. From the total weight, the percentage of tin is calculated.

The tin button may not be pure, as, if iron, copper, lead, wolfram, etc., are present they will be partly reduced and increase the weight of the button. These impurities may of course be removed by aquaregia before smelting, as mentioned in the cyanide assay of black tin. They have a bearing on the price obtainable for the black tin from the smelters; and therefore it is important to know the character and amount of interfering metals in the black oxide when dressed for market.

The total annual production of tin is about 100,000 tons.

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* If reduced tin is heated too long, there is a heavy loss.

TITANIUM.

Titanium.—This metal usually occurs as titaniferous iron ore.

The commercial value is but small and an ore must be of very high percentage to find ready sale. It has a very limited application in iron and steel manufacture, titanium in some cases producing a remarkable degree of toughness, and by some authorities being esteemed as a deoxidiser.

Rutile, oxide of titanium, is somewhat similar in appearance to cassiterite, but of lower specific gravity.

The chief ores of titanium are rutile and titaniferous iron. Rutile, colour brown, yellow and black streak, pale brown.

Titaniferous iron ore, usually in form of dark sand, sometimes in thin scaly plates, colour dark brown to black.

Ilmenite, or titaniferous iron ore, is described among the black minerals.

Some of the titanium minerals are somewhat insoluble in acids, but can readily be rendered soluble by fusion with acid potassium sulphate, extraction with cold water, diluting largely, neutralizing with ammonia (which precipitates the titanium together with iron and other substances), then slightly acidifying with sulphuric acid. If this solution be reduced by means of metallic zinc, the pale violet hue will gradually develop.

TUNGSTEN.

Tungsten (Wolframium).—Tungsten has recently come into prominence on account of its property of hardening steel when mixed with it in comparatively small proportions.

The chief ore is wolfram, a double tungstate of iron and manganese. When pure this ore contains about 75 per cent. of tungstic acid. To command a good price it must contain from 65 to 70 per cent. of tungstic acid and be as free as possible from arsenic and sulphur.

It often resembles cassiterite in its specific gravity and occurs with it. When this is the case the two minerals cannot be satisfactorily separated by the action of water, and it was formerly the practice to roast the ore with soda so as to convert the wolfram into tungstate of soda, which is soluble in water. Now-a-days the wolfram is separated from the cassiterite by the aid of a magnetic separator.

Ferberite is an iron-manganese tungstate very similar to wolfram. *Hübnerite* is manganese tungstate. *Stolzite* is lead tungstate.

The following method of assay will be found suitable for wolfram and scheelite, and the mixtures of wolfram with cassiterite that have sometimes to be examined.

After carefully sampling, grind a small quantity of the sample to the *finest possible powder* in the agate mortar. Weigh out 1 gram and boil for eight hours in a covered beaker, with 20 c.c. of pure hydrochloric acid and 5 c.c. of nitric acid, adding more acids as required. There is a tendency for the powdered ore to clot together and stick to the bottom of the beaker. It will be found convenient to add some small pieces of clean quartz, and to stir once or twice an hour.

At the end of the operation remove the cover and evaporate to dryness. Add a little more hydrochloric acid, warm to boiling, dilute to 100 c.c. with water, filter and wash thoroughly with hot water on the filter. The filtrate contains iron, manganese, lime, etc., in solution. The yellow insoluble matter on the filter is tungstic acid with any cassiterite that may be present, and probably a little silica. The filter is then treated with a warm solution of ammonia, and very thoroughly washed with hot water containing a little ammonia. This may be done by pouring the ammonia solution on the filter.

The filtrate is cautiously evaporated in a platinum dish, dried and carefully heated to redness on a burner for 5 minutes. The filter is carefully burnt and the ashes are treated again with acids in the same manner as the original ore, the whole process of acid solution, filtration, and digestion in ammonia being repeated. The second filtrate is added to the first.

Any insoluble residue left after the second treatment ought to be white* or nearly so, and should be tested for tin. [If tin is found a larger quantity should be finely ground and treated in the same way so as to obtain sufficient cassiterite to make an estimation of tin.]

The ignited tungstic acid may contain a little silica, which may be removed by a prolonged boiling with solution of carbonate of ammonia, in which tungstic acid is slowly soluble, but in which silica is insoluble.

The estimation of tungstic acid in wolfram and other tungsten compounds is one that requires considerable skill, and correct results cannot be obtained without considerable practice.

Scheelite, the only other ore of much commercial importance, is a heavy white mineral, containing 80 per cent. of tungstic acid in combination with lime. While usually white it may have a yellowish, reddish or greenish tint.

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* This white residue may consist of niobic acid and of silica in a very fine state of division; it is rather liable to pass through the filter, and the best Swedish filter paper should be used.

Treated with aquaregia it is decomposed, leaving a canary-coloured residue of tungstic acid, which is soluble in ammonia. When scheelite carries copper, it is known as cuproscheelite.

Both wolfram and scheelite are sold on the percentage of tungstic acid which they contain. The price fluctuates, greatly at present it is about 25s. per unit of tungstic acid.

The present world's production of tungsten ore is over 5,000 tons, and is steadily increasing.

URANIUM.

Uranium.—Uranium occurs principally as pitchblende, which when fairly pure contains from 70 to 80 per cent. of uranium oxide. It also usually contains varying percentages of manganese, iron and lead, and sometimes thorium, etc. Uranium ochre, as a yellowish or greenish-yellow incrustation, is also found on the upper portion of lodes carrying pitchblende.

Copper uranite (torbernite) is found in small quantities, and autunite (calcium uranite) has been found in larger quantities.

Carnotite is another rare mineral containing uranium, and uranium has also been found in certain other very rare minerals. These minerals have already been described.

Gummite is essentially an impure silicate of uranium with various heavy metals; it is an orange or brownish material, it is soft, and the specific gravity is about 4·0. It gives the microcosmic bead tests for uranium after purification (*see under* "Pitchblende"); it does not melt before the blowpipe. It dissolves in hydrochloric acid.

In testing any compound for uranium it is not advisable to trust to borax bead or microcosmic bead tests performed on the original mineral, for fear of the reactions being obscured by the other metals.

The mineral should first be dissolved in aqua-regia (or, if insoluble, it must first be fused with carbonate of soda) and the solution treated to remove some of the interfering metals.

The solution should be rendered nearly neutral with ammonia and then boiled with an excess of ammonium carbonate.

This will precipitate most of the metals, but the uranium will remain in solution. After filtering, the filtrate is acidified with hydrochloric acid and boiled, cooled and made alkaline with ammonia, when the uranium is thrown down as uranium hydrate, a pale yellow precipitate, which is filtered off, well washed with water containing a little ammonium chloride, and dried. On ignition it is converted into a greenish-black uranium oxide. This may then be tested in the borax and microcosmic beads.

	With borax—	With microcosmic salt—
In oxidising flame -	Yellow.	Yellow.
In reducing flame -	Green.	Green.

The uses of uranium are limited. It is employed in colouring glass and porcelain, and to a small extent in photography and chemical analysis. Radium is extracted from uranium ores, or their residues.

The value of a uranium ore would probably be considerable. Pitchblende is said to be worth £8 a unit (*i.e.*, £8 for each per cent. of uranium it contains).

The acetate, nitrate and oxide of uranium are sold commercially.

Radium.—It appears that all the uranium ores contain radium. This element (?) and its salts possess very remarkable qualities, and the interest that they have aroused has caused a vigorous search to be made for uranium ores.

The quantity of radium contained in pitchblende and other uranium ores is very small.

Many experiments have been tried in the hope that the radium emanations might prove of benefit in certain complaints, and some encouraging results have apparently been arrived at, but the thing is still in its infancy.

The emanations of radium and of the ores of uranium may be rendered visible by placing uranium ores in powder (or in lumps) close to a sensitive screen of zinc sulphide. On observing this screen in the dark, the emanations may be seen like small sparks striking against the screen. Somewhat similar appearances are seen with thorium compounds, and these sensitive screens may be useful in the detection of uranium and thorium ores. It is not yet, however, entirely established how far the method is applicable to all the ores of these metals and how small a percentage they will effectually indicate.

VANADIUM.

Vanadium.—This rare metal has recently received attention owing to the fact that a small proportion of vanadium added to a nickel steel produces a steel of very high tensile properties.

The following minerals contain vanadium :—

Vanadinite, chloro-vanadate of lead, reddish or brownish, soft and heavy.

Dechenite, vanadate of lead and zinc, brownish red, soft and heavy.

Carnotite is a compound of uranium and vanadium with potassium.

Mottramite, vanadate of lead and copper, a blackish incrustation in sandstone.

Descloizite, lead vanadate.

Volborthite is a compound of vanadium and copper.

Patronite is a name given to an impure compound of vanadium and sulphur, found in Peru.

A deposit of considerable size is now being worked in San Miguel County, Colorado. The ore is carnotite, and exists in sandstone, which contains from 2·5 to 4·5 per cent. of vanadium.

To examine any ore for vanadium it should be finely powdered and fused with nitrate of potash. The melt is then extracted with water, which will dissolve the potassium vanadate. A solution of barium chloride is added, and barium vanadate is precipitated. This is boiled with dilute sulphuric acid, filtered, neutralised with ammonia, and solid ammonium chloride added. Ammonium vanadate separates as a grey or pale brown body, and is filtered off. On igniting this vanadic oxide (V_2O_5) is left, which contains 56 per cent. of vanadium.*

The vanadic acid so separated should on testing in a microcosmic salt bead give an amber colour in the oxidising, and a green in the reducing flame.

The vanadates of the alkali metals are yellow salts, and dissolve in water, giving a yellow solution which, when acted on by a reducing agent, turns from yellow to blue.

The consumption of vanadium, though at present small, is increasing, and any new discoveries would deserve careful attention.

ZINC.

Zinc.—This metal is never found native, but the sulphide is found in large quantities in the United Kingdom, on the Continent, and in America.

Zinc is employed for "galvanising iron," used instead of copper for roofing, for the manufacture of various articles, and for the preparation of brass and other alloys.

The world's consumption of zinc is at present about 800,000 tons, and the present price is about £25 per ton; it has not varied much for some years.

The chief ore is *zinc sulphide*, commonly called zinc blende, or "Black Jack." The value of blende, dressed for market, is about £8 per ton. The English ores are usually yellowish-brown or brownish-black† in colour, and often have a resinous appearance, with a specific gravity of about 4·0. They have a semi-resinous fracture and sub-metallic or adamantine lustre. Hardness about the same as fluorspar, or rather less.

Zinc blende is not always black, although usually so, but other colours are met with in the case of foreign ores, reddish, yellowish, and greenish colours having been met with.

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* This method may be employed for the estimation of vanadium. J. J. Berringer, "Text-book of Assaying."

† The blackish-brown ores found in Cornwall contain more iron and are of lower value than the paler varieties found in North Wales and elsewhere.

Zinc blende is soluble in hydrochloric acid, with evolution of sulphuretted hydrogen.

When blende is strongly heated in air, the sulphur is partially expelled, leaving zinc oxide, with some sulphate. Heated on charcoal with access of air, it does not yield metal, but gives a whitish incrustation (yellow while hot). If this incrustation is moistened with a drop of a cobalt solution and strongly heated, the white colour of the incrustation is changed to a bright green. This is characteristic of zinc compounds.

Assay of zinc ores. Weigh 1 gram of the finely-powdered ore into a conical flask, decompose with hydrochloric acid and a few drops of nitric acid, then add a few drops of sulphuric acid and evaporate nearly to dryness. Take up with dilute hydrochloric acid, and pass sulphuretted hydrogen, filter, boil filtrate free from sulphuretted hydrogen, add a few drops of nitric acid, and boil again.

Add ammonium chloride and ammonia and boil, filter, redissolve and reprecipitate the iron obtained, adding the filtrate to the main bulk.

Cautiously neutralise the whole of the filtrate with hydrochloric acid, add 8 cc. in excess, heat nearly to boiling and titrate with standard potassium ferrocyanide until a drop of the solution, withdrawn from the assay, is found to give a brown coloration with a drop of uranium acetate solution on a porcelain plate. If manganese is present in the ore it is necessary to precipitate it by means of bromine from the ammoniacal solution obtained after the precipitation of the iron. The standard solution of ferrocyanide is made by dissolving 43·2 grams in 1,000 cc. of water, 1 cc. of this solution should be equivalent to 0·01 gram of zinc, and it may be exactly standardised by the use of pure zinc. The test solution of acetate is made by dissolving 0·2 gram of this salt in 100 cc. of water.

The process commercially in use for preparing zinc is to distil the calcined ore, mixed with finely ground anthracite, in cylindrical fireclay retorts with fireclay adapters, in which the metal condenses.

Calamine, or carbonate of zinc, is the ore next in importance to zinc blende. It gives off carbonic acid gas on treatment with any acid or on roasting.

Silicate of Zinc is also found. The hydrated variety is known as electric calamine, and the name Troostite is applied to the anhydrous silicate.

Spartalite, also known as *Zincite*, is an oxide of zinc containing a little manganese and iron. It is soluble in hydrochloric acid, and gives the ordinary white zinc oxide incrustation on charcoal, which is turned green on moistening with a cobalt salt and igniting.

Electric Calamine, Smithsonite, Hemimorphite, and Troosite are zinc silicates. They are whitish in colour if fairly pure, but are also of yellowish and brownish tints. They are decomposed by hydrochloric acid, the silica being converted into a gelatinous mass.

Cadmium is a comparatively rare metal associated with zinc. It has the property of forming alloys with a low melting point. Greenockite is an impure cadmium sulphide.

ZIRCONIUM.

Zirconium.—Zircon is the silicate of zirconium. It occurs usually in the form of sand, or of pebbles. When zircon occurs in pebbles of a clear white or yellow, it is cut into gem stones, and the variety found in Ceylon of a hyacinth colour is called a jargoon.

Zirconia, the oxide, was formerly used for incandescent mantle-making, as it glows intensely on ignition. Now its place is taken by thorium and allied minerals, which are more brilliant.

Zircon, the silicate of zirconium, is usually colourless, but also of a greyish, greenish, or brownish tint, rarely reddish.

The lustre is adamantine. Zircon is hard. It is usually found in the form of a fine, sparkling sand, or in small pebbles. The specific gravity is about 4·7. Large, clear pieces are cut for use as jewels.

There appears to be a limited demand for zircon sand, the price being variable and generally low. There are large quantities which could be raised very cheaply if a fresh use for it were discovered.

Zircon is not attacked by acids, but it is decomposed on fusion with sodium carbonate, and the melt on treatment with a slight excess of hydrochloric acid gives an orange colour to turmeric paper.

CONDITIONS UNDER WHICH MINERAL DEPOSITS OCCUR.

Conditions under which Mining Operations can be undertaken with reasonable prospects of success.

When a mineral deposit has been found it is necessary first to ascertain its extent and whether the metal or metals are present in a sufficient quantity as to render their extraction profitable. In the monograph on each metal the commercial value of the metal has been given, but it will be at once apparent that local conditions will have a material bearing on the ultimate prospect of profitable working.

Granted that a deposit of a commercial mineral has been discovered and that mining rights have been secured, we come next to consider a number of practical points that must receive attention before any prudent person would expend money further than in prospecting operations.

1. What is the thickness or width of the lode? How far can it be traced? Or, if an alluvial deposit, what is its depth and extent?
2. What is the average value of the lode-stuff or alluvium? That is to say, what percentage of metal or commercially saleable mineral does it carry? Can the mineral be concentrated with ordinary apparatus and without unusual loss? *
3. Is water power available, and does it exist all the year round or only during a limited season?
4. If water power is not available, is there a sufficient supply of timber or coal for running steam engines?
5. Is there sufficient clean water for dressing the ore?
6. What are the labour conditions? Is the country healthy for white men, and if not, can a suitable supply of native labour be obtained so that whites will only be required for supervision?

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* This point is of particular importance. The prospector must remember that some ores are so complex in their character that, although they may carry what seems to be a payable percentage of one, two or more minerals, it is necessary for these to be brought into a *marketable* condition, and if they cannot be dressed mechanically so as to yield *saleable* products of ordinary commercial purity, they may have but little value or possibly none at all.

7. What is the distance from the nearest navigable river or from the railway? Are there roads or only bush tracks? If the latter, is the country liable to severe floods, or particularly swampy or mountainous?

The question of transport is specially deserving of consideration, as in almost all mines it is necessary to employ crushing machinery; and though this is now constructed in sectional parts that can be transported easily and put together on arrival, machinery so constructed is not so rigid or so lasting as when such subdivision is unnecessary. In many cases where transport is a difficulty owing to the absence of proper roads, it would be possible to overcome the difficulty by laying a light tramway, and even if the trucks have to be propelled by manual labour the increased rapidity of transport and its greater certainty of arrival than when entrusted to carriers will quickly repay the outlay.

The actual discoverer of a mineral deposit may not have to undertake its development; but in presenting his discovery to capitalists as a practical proposition, he should remember that the above considerations will largely govern the practical chances of successful and profitable working, and therefore, in addition to bringing forward evidence as to the richness and extent of the mineral deposit he has discovered, he should be able to furnish full particulars as to its accessibility, and local conditions as to power, water supply, labour available, etc.

These considerations, and many others which have a close bearing on the probability of successfully operating any given deposit of mineral, have to be dealt with by the mining engineer, who is consulted by the prospector, or by the investors to whom the prospector brings his discovery, and the more complete the information that the prospector can give on all such details the greater is the chance of his discovery receiving serious attention. He should, therefore, make notes of all these matters, that he is able, while still on the spot, and supplement his notes by every means in his power, bearing in mind that however convinced he may be in his own mind regarding his discovery, he has to convince others, who have perhaps had a greater experience than his own, and who have to weigh the difficulties and risks that necessarily, in some degree, attend every mining operation, against the apparent chances of success.

MINING, MILLING, AND DRESSING.

[This section refers to the dressing of most ores except gold, which is separately dealt with in the Appendix.]

DESCRIPTION OF CERTAIN MINING TERMS.

Shafts, Adits, etc.—In sinking shafts for prospecting purposes it is seldom necessary to remove such a large portion of the ore body as would be required if the shaft were sunk for the purpose of haulage and pumping.

Before sinking a shaft the prospector will do well to thoroughly examine the "find," and if possible make a rough survey with the aid of a simple level, such as the "Abney" level, so as to find the most favourable spot for sinking. He may in some cases, be able to "drive right in" to a lode. The method he may decide to adopt must be decided by the local conditions that prevail. If it so happens that the work he undertakes can be subsequently utilised in opening up the mine, so much the better, but the laying out of a mine is not the first consideration for the prospector, which is to prove the value of the deposit in the quickest and cheapest manner consistent with safety.

The shaft is usually sunk on the lode, as in most cases this will better enable the prospector to obtain an idea as to its width and value than if the shaft be sunk vertically and the lode reached by cross-cutting. If several leaders appear on the surface within short distances it may be preferable to sink vertically and cross-cut.

The timbering of a small shaft,* provided the walls are fairly good, does not require the substantial structures used where large shafts are sunk, and may often consist of planking cut to suitable lengths, the planks being held in their places by corner pieces firmly nailed to them. The ore is removed by the pick, "gads," or wedges of steel, or, if very hard, is blasted away by explosives, suitable holes being drilled at angles which give to the explosive the greatest power to do the work required. In commencing work a wedge-shaped portion in the centre of the space marked out is first drilled and blasted away, and

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* It is no use attempting to sink too small a shaft, and the dimensions 6½ ft. by 4½ ft., will be found as small as is consistent with convenient room to work.

subsequently the remaining portions of the lode are removed in the same way until the space excavated is of the required dimensions. The same procedure is followed until the required depth is attained. After the first few feet are sunk, it is, of course, necessary to erect a small windlass at the top of the shaft for the removal of the ore.

A prospecting "level" or tunnel driven on the course of the lode or cross-cutting through the country need not, as in the case of a prospecting shaft, be of greater width than is necessary for working space.

In hard ground timbering may be unnecessary, but in soft ground supports to the roof and sometimes the walls must be inserted.

To support the roof and walls two "legs" are cut and inserted in shallow holes in the level, and cross-pieces known as "caps" placed across them. Should the roof and walls be weak, the spaces between each set of timbers are filled up with small poles or planks termed "laths." A level is often driven into the side of a hill either for the purpose of entering the mine or in order to avoid raising the ore, etc., to the top of a shaft sunk higher up the hill. The term "adit" is generally applied to a level driven in for draining that portion of the mine which is above it and for tramming out the ore, etc.

When a mine is worked down below adit level it is usually customary to pump most of the water up to the adit level only, so as to avoid the waste of power involved in pumping it all up to the top of the shaft.

"Winzes" are small shafts sunk, for the purpose of ventilation, from one level to another. "Rises" are communications made upwards.

A "stope" is an excavation for the removal of ore bodies. Two methods of stoping are in use, "overhand" or "back stoping" and "underhand stoping."

Overhand stoping is usually commenced by putting up a rise in the level and working away a sufficient quantity of the lode until it is possible to erect a platform above the level on which the miners stand to work. This method has the advantage that no haulage is necessary, as "passes" are constructed so as to allow the ore to pass into "chutes" or "shoots" placed in the level, from which the ore may be trammed away.

No "deads" (rubbish) need be removed, as these are allowed to remain on the "stulls" and form a continually rising working platform as the stopes are worked upwards. The chief disadvantage of overhand stoping is that valuable fragments of ore may become lost unless the *débris* is carefully picked over. Underhand stoping is not often followed, and consists in sinking on the floor of the level, usually in a series of steps. The whole

of the ore body broken must be removed by haulage, and the presence of much water in the level renders working a matter of great difficulty.

THE DRESSING OF LODE-STUFF FOR MARKET.

If the mineral that it is desired to extract is disseminated finely throughout rock, it will of course be necessary to crush it finely, because each particle of mineral must be set free from its adherent gangue. As mentioned before, it is of the greatest importance not to break the mineral particles more than is absolutely unavoidable. It is comparatively easy to separate particles of mineral and gangue, which are not much smaller than common sand, but when smaller particles, such as slimes, have to be dealt with, the same forms of apparatus are not effective, and it is much harder to prevent loss of mineral.

Sometimes it is possible to avoid breaking the larger pieces of ore, if they are rich enough to go to the smelter, and to trim away any adherent gangue with a hammer, or if the particles of ore disseminated throughout the rock are not too small, the rock may be coarsely crushed by rolls, say to a ½-inch or ⅛-inch mesh, and separation effected (of at any rate a portion of ore) by "jigging."

The "jig" is an apparatus in which the broken ore is placed with water, and given an up-and-down pulsating movement. This causes the mineral (the heavier portion) to arrange itself at the bottom and the lighter portion or gangue at the top, while between these is a layer of "middlings."

If the conditions are favourable, the mineral from the bottom of the jig may be clean enough to go direct to the ore-bin,* and the gangue can be run to the waste dump, the middlings only requiring further treatment.

Jigs are generally employed where the particles of ore and gangue to be separated are larger than ordinary sand, say about the size of wheat. For smaller particles than these, shaking tables are more often employed. Before considering these it will be convenient to consider briefly the other forms of concentrating appliances of older types which are still largely employed.

The earliest and simplest form of dressing apparatus was probably the strip or strake, which is nothing more than a trough which sometimes has "riffles" or cross-bars placed in the bottom to prevent the flow of pulp from being too rapid and to give the mineral portion time to settle.

Its use was in all probability suggested by observing the natural concentration that takes place in streams and waterways.

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* The place where dressed ore is stored ready to be sent away to the smelter or buyer.

In the case of the majority of ores the desired mineral is often so disseminated throughout the rock that the whole of the lode-stuff has to go through the mill or whatever crushing appliance is in use. Where labour is reasonably cheap hand picking may be resorted to. Hand picking is practically a necessity in the case of ores that slime badly, and is generally employed in the case of galena, copper ore, etc.

The ordinary stamp-mill is the appliance most generally in use. A visit to a mill in operation should be made when opportunity offers, and the various forms of dressing appliances should also be inspected.

There are two forms of stamp mill in common use, the Cornish and the Californian.*

The former is the older pattern and is still in use in some mines in Cornwall and elsewhere.. The Californian mill is similar to it, but is an improved type and is used in most modern installations. The difference between the two types is that, whereas in the Cornish stamps the "shoe" or head (the part which actually strikes the ore) is rectangular, in the Californian stamp it is cylindrical, and the shoe with its head and stem is caused to rotate slightly each time the stamp is lifted, thus ensuring more even wear and a more effective blow. In the Cornish stamp there is often no "die" (or steel block) underneath the ore which is being crushed, but only a hardened foundation made by throwing in pieces of any hard rock on which the stamp is allowed to beat till they have bedded hard together. In the Californian stamp-mill a steel die is placed in the mortar box, so that the lumps of ore are broken between two hard steel surfaces, and consequently this type of stamp will, weight for weight, get through much more rock than the older Cornish pattern. A Californian stamp-mill consists of a series of batteries, each containing a number of stamps, usually five in each battery. Each stamp consists of a stem (with a head and "shoe" attached at its lower end) and "tappet" by which the stamp is raised by the action of a cam fixed in the cam shaft. As the shaft revolves the cam engages the tappet and lifts the stamp up from 6 to 9 inches and then lets it fall. The cams are arranged so that the stamps rise and fall in a certain order, *i.e.*, so that the stamps are not all lifted at once, but at regular intervals, in order that the work done in lifting them may be even and regular throughout the whole rotation of the shaft.

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* The Patent Improved Air Cushion Stamper, manufactured by Messrs. Holman Brothers, Ltd., of Camborne, is rapidly forging ahead and has become very popular in many mining centres. This is probably due to the fact that in its smaller sizes the prospector finds a very effective crushing appliance, which can be easily handled, and accomplishes a surprising amount of work at a very moderate upkeep.

The stem travels up and down in guides which may be either wood or metal and must, like the cams and tappets, be kept well lubricated.

The die, on which the ore is broken, is placed within the "mortar-box," which is a box formed of iron or steel plates and serves to contain the ore until it has been broken fine enough to pass through the sieves or "screens" which are arranged in the front, back, or at the sides of the mortar-box. Water is admitted into the mortar-box with the ore, and as the ore gets broken into small particles, these particles become suspended in the water, and each time the stamp falls some of this water is splashed up against the screen and some of the finely divided ore passes through. If it were possible to ensure that every particle of ore should be washed out of the mortar-box and through the screen directly it was broken small enough to pass the screen, it would be a great advantage, but many of the particles both of mineral and gangue fall back under the shoe and are broken again, so that the mixture of stamped ore and water (usually termed "pulp") which issues from the screens always contains a certain amount of very finely divided particles of ore and gangue. The larger particles of the "pulp" which would remain in a pan if stirred up several times with water and gently tilted, are usually called the "sands," while the lighter portion or very fine mud is termed the "slimes." Both sands and slimes contain mineral particles, and to obtain a good extraction, *i.e.*, to avoid waste of the mineral, it is usually necessary to treat the sands and slimes separately.

Before the ore is fed into the stamps it must be broken to a convenient size. This is accomplished either by breaking the larger stones by hand with a spalling-hammer, or in larger mills by passing the whole of the ore as it comes from the mine in the trucks over a "grizzly," a grating of steel bars set close enough together to prevent the passage of pieces too large to go direct to the stamps. For ordinary sized stamps no pieces of ore should exceed from 1½ inches to 2 inches. Those stones that do not pass the "grizzly" fall into the stone-breaker. One type of rock-breaker is a machine consisting essentially of two steel jaws, one of which is fixed, while the other advances and recedes, being operated by a toggle-action, and fitted with a heavy fly-wheel. The machine may, in fact, be likened to a nut-cracker on a large scale.

Another type of rock-breaker is that known as the "Gates," in which the gyratory movement of a steel rod breaks the ore against a steel cup.

The amount of ore that each stamp is capable of crushing will depend on the size (weight) of the stamp, the hardness of the ore, and the size to which it is considered necessary to stamp the

ore. The battery manager has to decide, from the nature of the ore, how to get the best work out of his battery by selecting the most effective height to allow the stamps to fall, the number of drops per minute and the amount of water to admit with the ore. It is essential to feed the ore *regularly* to the stamps. If it is fed too rapidly, the stamps will not have sufficient fall to enable them to do their best work. If they are allowed to go on dropping and sufficient ore is not fed in, the shoe will eventually beat on the die without any ore between them, and possibly crack it, the mill being exposed to unnecessary and dangerous vibration. The stamp mill is practically a series of large pestles and mortars, into which the ore is continually fed, and the pulverised ore continually removed by being washed away with water.

Stamp mills vary in size from very small prospecting stamps that can be worked by hand, in which the total weight of the stamp (stem, tappet, and shoe) may be 60 lbs., up to the largest size, in which the total weight may be 1,250 lbs., or more. The amount of ore that can be crushed by the latter in the case of moderately hard stone is about 5 tons in the 24 hours.

The wearing parts, namely, the shoes and dies, require replacing according to the hardness of the ore, and may last from 50 to 100 days. It is important that the mill should be protected as far as possible from sun and rain, and it should therefore be covered by a roof of boards or galvanised iron.

While the stamp-mill is employed at the majority of mines, and is generally found to be the most economical and effective apparatus for general work, for certain classes of ore, ball-mills and rolls are more suitable and have the advantage that it is easier to regulate the size of the particles produced. Thus, in a blende or galena mine where much of the ore need not be crushed much finer than the size of peas, rolls would be useful, as it is always better not to break the ore more than is essential, and if the mineral is in fairly large particles a good deal of it can be separated by jigging, whereas if it were put through a stamp mill the particles would be smaller than could suitably be treated in a jig. Rolls and ball mills also have the advantage of producing a more uniform size of particles, which is very important, because there is but little loss in separating mineral and gangue if the particles of each are not much smaller than ordinary sand, whereas when both mineral and gangue are very fine (slimes) it is much harder to separate the mineral without serious loss.

When the mineral is so finely disseminated in the rock that the lode-stuff has to be stamped to pass a 20 mesh, jigs would not be suitable, and either buddles, vanners or shaking tables would be employed for the treatment of the larger particles (the sands) and slime tables or "ragging" frames for the slimes.

The Cornish buddle is still used to a considerable extent on account of its simple and cheap construction. The chief objection to its use is that it fails to save the finer particles and that the concentrate has to be treated several times over at a large expense in labour.

The Cornish buddle consists of a circular pit or pond from 10 to 20 feet in diameter with a revolving cast-iron centre piece furnished with arms carrying brushes which assist to keep the surface of the pile of sands uniform and even.

The pulp flows on to the middle of the revolving centre-piece and is distributed uniformly all round it, making a mound which gradually fills up the whole buddle. The slimes and water are partly ponded back so that the mould is under water round the edges all the time it is forming.

When the buddle is full, the flow of pulp is stopped and the water (with most of the slimes) is drained off. It will then be found that the mineral is chiefly distributed near the centre-piece, while towards the outer edge the gangue is nearly free from mineral. The man in charge then tests the buddle by "vanning" and draws a ring round it to mark off the part nearest the circumference which can be thrown away, and the upper portion is also generally separated into the "head" and "middle-head," both of which will require re-buddling, perhaps half-a-dozen times, before they are fit to go into the ore-bin. It has already been stated that slimes, and in fact "fines," that is fine sand, cannot be treated successfully in the buddle, nor can particles much larger than ordinary sand. When it is desired to dress particles of ore larger than sand the jig (already described) is suitable, or concentration may be effected in a "tye," which is practically a short sluice-box. In the latter apparatus they have, however, to be worked over several times with a great expenditure of labour.

It has been long recognised that the labour expended on buddling was responsible for a large part of the cost of tin dressing, and many forms of apparatus have been devised with the intention both of minimising the hand-labour involved, and secondly, of obtaining a purer product in a single operation.

One of the earliest forms of mechanical apparatus was probably the Brunton Cloth, a continuous belt on which the pulp was delivered, and the lighter particles of gangue were washed off by a stream of water. This machine did not require much attention, but the head or concentrate was not very pure and required re-treatment, and the loss in the tailings was probably considerable.

This machine was first in use some 60 years ago. Later followed the Embrey Concentrator, and later still the Frue Vanner.

This machine has been largely employed for a great variety of minerals and does very good work. It appears now, however, to be giving way to the modern forms of shaking table.

The Frue Vanner consists of a long belt of rubber on which the pulp is delivered.

Wash-water is applied and a lateral shake given to keep the mineral bed loose. The gangue is washed off the belt at the end, and the concentrate is delivered into a box filled with water into which the concentrate falls off and is collected.

The expense of the rubber belt and the small capacity of the vanner are the two chief objections to it. In addition, only two products (heads and tails) can be made, whereas in the pulp there are almost always three distinct classes of product (besides the slimes), namely, (1) clean mineral, (2) clean sands free from mineral, and (3) middlings, or particles which consist partly of ore and partly of gangue.*

In the modern forms of shaking table it is possible to collect these three classes separately. There are a large number of shaking tables, some of which are used very extensively. Some of the better known types are the Wilfley, the Overstrom, the Buss, the Triumph, and the Record.

In judging of the efficiency of a shaking table for a particular class of ore, the following points should be studied, some three or four tons being run over the table:—

(1) The richness or purity of the concentrate.
(2) The loss in the tailings.
(3) The capacity of the table.

1. If there is only one mineral to be saved, the head or concentrate may be rich enough to go direct to the ore-bin. If there are two minerals (such as galena and blende) at least one of them should be clean enough to require no further treatment.

2. There ought to be the least possible loss in the tailings, as otherwise they will require re-treatment on a separate form of apparatus. The amount of permissible or unavoidable loss will naturally vary with the class and value of ore that is being treated, but it is a point of the highest importance and one that may make the difference between a profit and a loss. Both when the plant is being selected and when it is in operation, the tails should be regularly assayed, or preventible losses are sure to occur.

3. There is a certain quantity of pulp that can be efficiently dealt with on each type of table, consistently with obtaining a rich head and clean tails, and in the case of each ore an

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* These often require re-grinding in a pan or pulveriser.

actual trial should be made, and the various products assayed, and examined microscopically.

From trials the author has witnessed with various ores on the Record Vanner (for which a specially large capacity is claimed) he is inclined to believe it to be the most effective table yet introduced for dealing with *large* quantities of pulp, and at the same time producing really satisfactory separations.

Slimes.—As has been stated above, whatever method of crushing is adopted, a certain proportion of very fine particles both of ore and gangue will be produced. These particles will not settle readily in water, and the mineral cannot be separated from the gangue so easily or with such certainty as is the case when the particles are the size of ordinary sea-sand.

To estimate the proportion of slimes to sands an average sample of pulp as it comes from the mill should be taken.

The sample is dried at a steam heat and a weighed portion (after careful mixing) is panned until all slimes have been eliminated, but without allowing any sand or mineral particle, except slimes, to leave the dish. The contents of the dish are then weighed; and the percentage of the slimes is obtained by subtraction. It is necessary to dry the slimes and assay them, as it often happens that they are allowed to flow to waste, and enormous quantities of mineral are thus lost.

Another portion of dried pulp is weighed and passed through sieves of standard mesh, using 30, 60, 90, 120 and 200 mesh sieves. All that which passes the 120 sieve may be regarded as slime.

There are not so many forms of apparatus for the treatment of slimes as there are for sands. Some of them depend on the adhesion of the mineral particles to a canvas belt or tray, which are afterwards removed by the passage of the belt through a water-trough. The capacity of slimes machines is usually small, and there is probably a good deal more loss in proportion than when sands are dealt with on a shaking table. Revolving tables and dead frames are at present best for slime concentrating. There is even more need for a practical trial of a proposed machine on the actual slimes that it is needed to treat than is the case when it is proposed to instal shaking tables for treating sands.

All ores tend to "slime" more or less; some, such as cinnabar and copper carbonate, so much so that wet treatment is nearly useless.

Whatever types of dressing appliances are used in the dressing and saving of any mineral, whether it be gold, copper, tin, lead, silver, etc., there is always a certain loss in the tailings.

Part of the actual loss may be impossible to prevent, but in a great many mines a careful study of the tailings would be repaid by an increased saving of mineral. To recover all that *is* possible requires, first, a series of tests to determine the right plant to employ, and secondly, continuous and systematic assays to make certain that it is being used to the best advantage, so as to alter the methods if there are changes in the character of the ore that make changes advantageous. In addition to chemical tests, a careful and systematic examination of the various sizes of sands under the microscope is very useful, as in this way it can be learned whether the mineral it is desired to extract is locked up in compound particles.

All such investigations should be conducted by a skilled metallurgist in consultation with the manager of the mine. On the care and completeness with which they are carried out, the success of many mines will largely depend, and it is of the highest importance that the assayer engaged on the mine should have the knowledge and ability to make it clear to the superintendent where avoidable losses occur and what steps should be taken to minimise them.

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APPENDIX.

APPENDIX.

NOTES ON THE EXTRACTION OF GOLD.

(Alluvial deposits; lode-stuff; milling and amalgamation; chlorination; cyaniding; etc.)

WHEN gold occurs in alluvial or in "placer" deposits, it is found in the forms of nuggets and grains of various sizes down to fine dust.

In such deposits it always exists as "free" gold, *i.e.*, not enclosed in pyrites as it may be when in lode-stuff.

Nuggets and large grains are very easily separated from the accompanying earth or sand by simple washing in a pan, cradle, or sluice, as the great difference between the specific gravity of gold and earth or sand, enables the latter to be readily washed away without loss of gold. When, however, the particles of gold are very small, there is a tendency for them to be washed away with the gangue, so that special means must be adopted to prevent this from happening.

Two general methods are in use, namely, amalgamation (which is dealt with further on), and the mechanical arrest of the gold particles by running the gold-bearing dirt or sand with water over some fabric such as burlap, canvas, carpet, or a hide (with the hair uppermost), so that the particles of gold may be caught in the interstices of the material which is carefully washed from time to time. Although gold found in alluvium is never or very rarely enclosed in pyrites, it is sometimes coated with rust, and may not amalgamate freely. In concentrating gold sands therefore, it is necessary to be very careful that no concentrates are discarded which still contain some gold. Such concentrates very often contain black iron sand, and it is highly desirable in any doubtful cases to make a fire-assay, or to roast the concentrates, and then boil them with hydrochloric acid, and pan the residue again.

If sands are being dealt with a careful look-out should be kept for platinum, osmiridium, cassiterite, and monazite. (The characters of all these have been detailed under their respective headings.)

It has already been explained (under "Gold"), how pyrites suspected to contain gold should be treated. It remains now to consider the methods employed when gold, both free and contained in pyrites, occurs in lode-formation.

The most common matrix of gold is quartz, in the form of quartzose veinstone or conglomerate; sometimes the quartz is white and very pure, at other times it contains much iron, which is often in the form of oxide near the surface, and pyrites further down. The surface rock is often rusty and cellular, owing to the decomposition and partial leaching away of the pyrites. To extract gold from lode-stuff, the ordinary stamp-mill is usually employed, and if the ore contains "free" gold, amalgamation is always part of the process.

When clean gold comes into contact with mercury it combines with it, forming "amalgam." Gold is actually soluble in mercury at ordinary temperatures to a small extent, namely, about ·1 per cent. If more gold is added the mixture becomes less fluid, and a more or less definite compound of gold and mercury when the proportion of gold to mercury reaches about 30 to 40 per cent. This compound is a heavy pasty solid, and is miscible with the saturated solution containing ·1 per cent. previously mentioned. The amalgam from the plates is ground with mercury and squeezed through canvas or wash-leather, the liquid mercury which runs through contains about ·1 per cent. of gold, and the solid amalgam still more or less mixed with the liquid one, remains as a pasty mass inside the fabric.

To insure good amalgamation it is usual to add mercury both to the mortar box and to the surface of copper plates placed outside it, as described below. Any amalgam which may be formed in the mortar box is partly deposited on internal copper plates. The remainder of the material in the form of sands and slimes ("pulp") escapes through the screens and flows over amalgamated copper plates arranged outside the mortar box, when the amalgam is collected by adhering to them. The balls of solid amalgam are placed in a retort and the mercury distilled off by heat. The copper plates over which the pulp is run are placed at such an angle that the material will run over them without settling, but the angle must not be so steep as to cause the pulp to run too fast, as the amalgam would have no chance of adhering to the plates. It is considered an advantage to have a succession of two or three plates with a drop of, say, an inch or two inches from the upper to the lower one, but the drop must not be too great or the fall of the sharp particles of sand will scour or cut the plate, and the amalgam will not be deposited on account of the abrasive action of the sand rubbing off the amalgam and exposing the bare copper.

The copper plates must be either pure copper or muntz metal copper 60 per cent., zinc 40 per cent.). Before they are placed in position, copper plates should be annealed (or heated slowly to a temperature below dull redness) in order to render their surface soft and porous.

After annealing, the plates are cleaned by rubbing with dilute acid, and when thoroughly bright are amalgamated by rubbing with mercury. To clean and also to amalgamate them, it is necessary to scour them well by rubbing on sand with a piece of wood, until the surface is quite bright and shining in every part. It is found in practice that the plate will catch gold best if it is amalgamated, not only with mercury but with a little gold or silver amalgam. Gold amalgam can be obtained in scales by heating an old plate on some hot sand and scraping off the gold amalgam as it becomes loosened; or silver amalgam can be easily made by allowing metallic mercury to remain in company with silver nitrate solution, and some pieces of bright hoop-iron. The silver is reduced and on stirring up becomes amalgamated with the mercury. A plate of actual silver could, of course, be employed, but it is expensive, because the plates must be flat, and would, therefore, have to be at least $\frac{1}{16}''$ thick.

Amalgamated copper plates are apt to develop local discolorations or stains occasionally in places, and when this happens the part affected must be re-amalgamated as it will not catch amalgam. The presence of impurities in the copper and of sulphides in the ores seem to be the cause of these stains, and they are best removed by rubbing the spots with a lump of potassium (or sodium) cyanide and then with a little mercury, until the spot is properly re-amalgamated. It is important that no greasy matter, such as candle ends or lubricating oil should get on the ore or in the mortar box, as a very little grease interferes with proper amalgamation.

When the mercury does not amalgamate properly with the gold, but becomes finely divided and "slimes," it is said to "flour" or "sicken." This may be due to the presence of acid in the water, or of certain base metals such as lead, iron, copper, and is a considerable cause of trouble, while the loss of mercury (and of amalgam) may become very serious. When this is due to the acidity of the water it may be remedied by adding a little lime with the ore, or sometimes by adding sodium-amalgam with the mercury. If sulphides are present in very large quantities it may be necessary to give up the use of mercury entirely, and to catch the free gold and the auriferous sulphides on blankets or carpets, and to grind them with mercury in a pan or to roast them so as to expel sulphur, and then grind with mercury.

In most gold ores there is a certain proportion of the metal "free" or uncombined, and a further proportion enclosed in (but not actually combined with) pyrites. If the ore does not cause serious sickening of mercury the pulp is generally run over amalgamated plates first, and then either over a shaking table or vanner to separate the auriferous sulphides; or the tailings and slimes may be separated and treated by the cyanide or chlorination methods.

Gold is soluble in chlorine water, bromine water, solution of potassium or sodium cyanide and in aqua-regia. For practical purposes only chlorine and potassium or sodium cyanides are used, and the latter is now chiefly employed because it dissolves gold easily without the necessity of mechanical agitation, and large quantities of tailings can be easily dealt with in open tanks.

Chlorination is more often resorted to when the ore contains much sulphides that would decompose cyanide solution. To obtain good results with chlorine the ore has to be revolved in barrels and the gas must be used under slight pressure so that the operation is not so simple as leaching (or soaking) the ore in open tanks with cyanide solution.

When gold-bearing tailings are treated with chlorine water a solution of chloride of gold is formed, which is boiled to expel chlorine and the gold is precipitated with ferrous sulphate or some other convenient chemical, the precipitate is filtered and smelted.

Cyaniding is practised as follows:—

The tailings after leaving the battery plates may be run into a dam, whence they are dug out and placed in vats, or they may be run direct into the cyaniding vats. In either case the slimes must be allowed to flow away at any rate partially, as they would be an obstacle to the passage of the solutions through the sands.

Cyanide vats are generally cylindrical steel tanks open at the top and fitted with a door at the bottom. There is a false bottom covered with a filter-cloth to prevent sand from choking the exit-pipes.

When the vat is filled with sand a solution of cyanide is pumped on to it and either allowed to remain at rest or circulated by the aid of a pump until it has dissolved the gold in the sands. The correct strength of solution to employ is a matter for experiment; much more dilute solutions are now used than formerly, a ·1 per cent. solution is generally convenient (2¼ lbs. of cyanide in a ton of water). After the solution leaves the cyanide vat the gold must be extracted from it: there are two methods by which this is done, first by precipitation on lead sheets by the aid of an electric current, or by chemical precipitation on zinc shavings. The latter plan is more commonly employed.

The zinc shavings are made by cutting off a thin shaving from discs of sheet zinc in a lathe. The zinc must be as pure as possible, and the shavings should be thin enough to burn if held in a spirit flame. The zinc shavings are packed fairly tightly in a box with several compartments, arranged so that the cyanide solution passes up through one and down through the next. The gold is deposited on the zinc as a blackish mud, and the zinc gradually becomes brittle and finally almost entirely dissolves, leaving a blackish mud, which consists of gold, particles of zinc, with various other impurities. This mud is collected carefully, washed to remove cyanide, dried and treated with weak sulphuric acid to remove undecomposed zinc, dried, mixed with fluxes, and smelted.

It usually contains after smelting from 75 to 90 per cent. of actual gold.

The solution after passing the zinc boxes runs into a tank, and its strength is restored to the original strength by adding a sufficient quantity of strong solution of cyanide, and it is used again and again until it becomes too impure, when it is thrown away. Care must naturally be exercised in its disposal on account of its poisonous qualities.

After the first leaching as described above, it is customary to leach a second time with a more dilute solution and finally with a wash of water, if this were not done a quantity of gold-bearing solution would be wasted, as the wet sands retain a good deal of liquid.

A test may be made on tailings by treatment of a weighed quantity in a large jar, so as to learn what proportion of the gold can be extracted by solutions of a given strength and how long the liquid must remain in contact. In this case the cyanide solution may be conveniently evaporated in a dish made by turning up the edges of a piece of pure lead sheet.

When the solution is dry the lead sheet is folded up, fused, scorified and cupelled. In addition to estimating the gold so recovered, it is essential that the tailings should be accurately assayed before and after cyaniding.

To extract gold from the slimes is not so easy as from sands, as they cannot be leached in tanks in the same way. One plan that is commonly adopted is to stir the slimes with cyanide solution, and then pass the liquid through a filter press, which retains the solid mud, the liquid containing the gold in solution being treated in zinc boxes as above described.

It may sometimes happen that gold ores are met with in which the gold cannot be extracted by amalgamation, or by chlorination or by cyaniding. In such cases, if a concentrate can be obtained sufficiently rich, it may be smelted with lead or litharge and the auriferous lead cupelled.

In whatever form gold occurs, and whatever methods are used for its extraction, when work is being conducted on a large scale it is of the highest importance that continuous assays should be made of the tailings, as if this is not done there is certain to be unnecessary loss of gold.

GENERAL NOTES ON MINERAL CRYSTALS.

By Donald MacAlister.

In the determination of minerals the prospector may be saved from the necessity of making chemical examinations by carefully noting their general physical characteristics as indicated by simple tests. The distinguishing features may be peculiarities of lustre, colour (both of streak and freshly broken surface), hardness, flexibility or malleability, nature of cleavage and fracture, specific gravity, magnetic properties, and, finally, of structure and form. The determination of these points, together with a few simple confirmatory blow-pipe tests, should place the identification of the mineral beyond doubt. Most minerals have a tendency to occur as crystals, *i.e.*, as solid bodies of definite geometrical forms bounded by plane, or occasionally curved, rectangular, rhomboidal, triangular or polygonal faces of all shapes.

In the mineral kingdom there is an infinite variety of crystalline forms, but, by means of certain observations with regard to symmetry, all crystals can be classified into six fundamental crystal-systems, in which there are 32 groups. As each mineral has definite optical properties depending in varying degrees on its colour and perculiarities of form of the crystal as well as in other ways, a careful examination by the polarising microscope is sufficient to reveal its identity. As, however, the use of the microscope is not acquired without more practice than most prospectors can afford the time for, this branch of the subject will be dismissed.

Before describing these crystal systems it will be well to first briefly indicate the different forms and so-called "habits" which minerals may assume, and first to refer to those which are amorphous or minutely-crystalline. Where the mineral occurs in lumps with no particular external form or internal structure it is referred to as being *massive*. If it is non-crystalline it is *amorphous*. When it occurs in spheroidal aggregates, often showing an internal radiating, fibrous structure and transverse banding, the form is indicated by such terms as *concretionary*, *nodular*, *botryoidal* (like a bunch of grapes), *reniform* (kidney-shaped), *mammillated* (large spheroidal surfaces). Sometimes the mineral occurs branching like a tree, in which case it is of *arborescent* form. Hair-like aggregates are spoken of as having *capillary*, *filiform* or *wiry* structures. When the mineral aggregate is built up of separable plates the structure is *tabular*, *lamellar*, *platy* or *scaly*. Such terms as *granular*, *columnar*, *lenticular*, *&c.*, do not need definition, as they are self-explanatory.

Returning to the well crystallized minerals, it should be observed that they may show modifications, forms or habits which differentiate them from others of the same crystal system. Thus, some crystals may be platy or tabular in form. Others may be long and narrow (*columnar*) and sometimes very fine (*acicular*, *fibrous*). Many crystals show the curious property known as twinning. In this case half the crystal may appear to have been turned round through 180° relatively to the other half, while in other cases there appear to be two crystals meeting or penetrating one another, the axes of the two individuals meeting one another at a definite angle, forming *geniculate* (knee-shaped) or *cruciform* twins. When parallel twinning is repeated several times it is known as lamellar twinning; while the growth together of several parallel crystals which are not twins is known as parallel grouping.

Another modification to which some mineral-crystals are liable is the development of only a half or rarely (in combination) a quarter of the normal number of crystal faces (hemihedral and tetartohedral forms). This is owing to the growth of alternate faces at the expense of the intervening faces which may be absent or occur as facets.

The principle upon which the classification of crystals is based is that of symmetry. The symmetry is determined with reference to certain planes (planes of symmetry), lines (axes of symmetry), or of a point within the crystal.

A plane of symmetry is a plane in a crystal which divides it into two similar parts so that each may be regarded as the reflection of the other. Many crystals have several planes of symmetry which intersect each other, and the lines of intersection are called axes of symmetry. If the crystal is rotated about an axis of symmetry it will be found that certain similar faces will occupy similar positions, and during a complete revolution will be seen to occupy these positions several times. The axis is one of binary, trigonal, tetragonal, or hexagonal symmetry, according as the faces appear twice, three, four, or six times.

In addition to this, crystals may more conveniently be defined with reference to what are known as crystallographic axes. Such axes are three imaginary lines (four in the hexagonal system) which intersect one another at a point in the crystal called the point of origin. In some cases, as in the cubic, tetragonal and rhombic systems, they happen to coincide with axes of symmetry, but they should be regarded independently as being related solely to the molecular structure (and, of course, optical properties), and directions of growth of the crystal.

Thus, if the triclinic system be taken as an example, it will be seen that there are no planes of symmetry, while there are three crystallographic axes mutually inclined to one another, and of different lengths. Exceptional cases are those of so-called false- or pseudo-symmetry in which such a crystal may appear to have symmetry, which is, in reality, an effect of twinning or a departure from true symmetry by such a small amount as to be scarcely noticeable. The effect of twinning is to increase the degree of symmetry.

The six crystal systems are named as follows:—*Cubic* (or regular), *Hexagonal*, *Tetragonal* (or orthorhombic), *Monoclinic* (or oblique), and *Triclinic* (or doubly-oblique).

As it is simpler to indicate the difference in the crystal systems by reference to their crystallographic axes, the degrees of symmetry will only be mentioned incidentally.

Cubic System.—In this system the three crystallographic axes are equal and at right angles to one another, the type form being the octahedron. In the octahedron it will be seen that there are nine planes of symmetry, six axes of binary symmetry, four of trigonal, and three of tetragonal, but there are variations in the degree of symmetry in the hemihedral modifications. The various forms of this system comprise the octahedron, the rhombic dodecahedron, etc., for illustrations and further descriptions of which works of mineralogy must be consulted (*e.g.*, "Elements of Mineralogy," by Frank Rutley). Garnet, galena, zincblende, pyrites, and tetrahedrite are examples of cubic minerals.

Hexagonal System.—In this system there are four crystallographic axes. The three lateral axes are in the same plane and are of equal length, each being inclined to the next at an angle of 60°. The principal or vertical axis is a fourth line of different length (shorter or longer) at right angles to the lateral axes. It is obvious that there are six vertical planes of symmetry and one of horizontal symmetry. One axis of hexagonal and six of binary symmetry. It should be pointed out, however, that there are two divisions in this system, known respectively as the normal hexagonal, and the trigonal (or rhombohedral) divisions respectively. The emerald, quartz, calcite, tourmaline, corundum, chalybite, etc.

Tetragonal System.—In this system there are three axes at right angles. The two lateral axes are equal, while the third principal or vertical axis is of different length to the other two. Zircon, copper pyrites, tin stone, etc.

Rhombic System.—There are three axes in this system, all at right angles and of unequal length. Barytes, göthite, sulphur, olivine, andalusite, aragonite, topaz, etc.

Monoclinic System.—Three unequal axes. The two lateral axes are at right angles while the principal axis is at right angles to only one of the lateral axes. There is only one plane of symmetry. Gypsum, monazite, epidote, augite, the micas, talc, orthoclase, etc.

Triclinic System.—All the axes are unequal in length and all are inclined to one another. There are no planes of symmetry. Axinite, plagioclase, etc.

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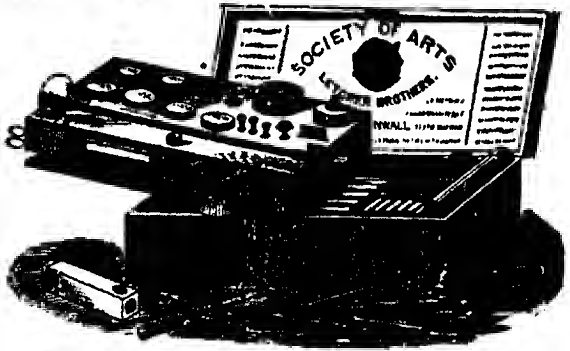

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